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AN APPROACH TO A DEFENSE DATA NETWORK FOR THE SAUDI MINISTRY OF DEFENSE AND AVIATION

by

Abdulrahman Abdullah Al-Najashi

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Thesis Advisor: Gary K. Poock

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Computer and data communication networks have become an integral part of the modern military structure. The technology of its software and hardware change rapidly. As a result, it is of paramount importance for the Saudi Ministry of Defense and Aviation (MODA) to remain abreast of such technology. Due to lack of actual data about MODA requirements, this theme is focused on the general concepts of computer and data communications networks. In addition, this thesis includes a detailed discussion of the U.S. DDN in order to provide guidelines for MODA if similar network design is to be developed. The framework of network-capacity planning is briefly described as well.

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An Approach to A Defense Data Network for the Saudi Ministry of Defense and Aviation

by

Abdulrahman Abdullah Al-Najashi
Captain, Saudi Arabian Air Defense Forces
B.S.E, Arizona State University, 1983

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Authors: ____________________
Abdulrahman Abdullah Al-Najashi

Approved by: Gary K Poock
Gary K. Poock, Thesis Advisor

Myung W Suh
Myung W. Suh, Second Reader

____
David R. Whipple, Chairman
Department of Administrative Sciences

ABSTRACT

Computer and data communication networks have become an integral part of the modern military structure. The technology of its software and hardware change rapidly. As a result, it is of paramount importance for the Saudi Ministry of Defense and Aviation (MODA) to remain abreast of such technology. Due to lack of actual data about MODA requirements, this theme is focused on the general concepts of computer and data communications networks. In addition, this thesis includes a detailed discussion of the U.S. DDN in order to provide guidelines for MODA if similar network design is to be developed. The framework of network-capacity planning is briefly described as well.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. HISTORICAL BACKGROUND IN TELECOMMUNICATIONS

Humans started using symbols to communicate with each other many years ago. Recorded history goes back to the year 15 BC when the Sceirites in the Red Sea basin developed a system of employing letters (symbols) arranged together to form sentences. That marked one of the first time when symbols were used as a form of written and oral communications [Ref. 1:p. 3]. Then, man used birds to carry messages. Carrier pigeons were trained to fly to distant destinations with written messages attached to their feet. As man sought knowledge by exploring the secrets and mysteries of mother nature, telegraphy, telephones and other means were invented to serve humans' needs and fulfill their requirements.

1. Telegraphy and Telephony

The idea of telegraphy came about around 1800 when a device called voltaic pile (a battery) that converted chemical energy to electrical energy provided a source of continuous electric current. Experiments between 1820 and 1840 were carried out to reveal the fact that as current flows in a wire, it causes movement in a magnet hanging freely nearby. Then the means of receiving signals was discovered with the invention of electromagnetic detectors in 1836-1837 by Sir William Cooke (1806-1879) and Sir Charles Wheatstone (1802-1875) in Britain and by Samuel F. Morse (1791-1872) in the United States.

The first successful telegraph communications took place in Great Britain with the Paddington-west Drayton line of July 1839. In the United States, the first successful telegraph communication was Morse's Baltimore-Washington line of 1844. Shortly, the telegraph was rapidly adopted in the European continent, in Asia as part of Great Britain's colonial Plans, and quickly spanned throughout the United States [Ref. 2:p. 208].

On the other hand the telephone is a device for reproducing sound at a distance from its source by means of the transmission of an electrical si   al. It was invented by Alexander Graham Bell in 1987. Bell realized that sound waves do not travel very far nor very fast so he had to come up with a way to convert sound waves to electrical oscillations which could be transmitted long distances 900,000 times faster than sound. At the destination, these oscillations were converted back into sound waves. Bell, with the assistance of Thomas A. Watson, succeeded in developing a practical telephone by making an electric current vary in intensity precisely as air varies in density during the production of sound [Ref. 3:p. 75].

2. Telegraphy and Telepho   in the Military

One of the earliest uses of telegraphy for military purposes took place in India in 1857 when the Indian revolution broke out against the colonial British occupation of India. The British Army responded quickly to contain the revolution in various locations of India by using the telegraph network, which was already established, as a means of strategic and tactical communications among military units to link all of them to the Command Center of the British government in Calcutta.

Another early use of telegraph in military operations was executed by the American government and its forces command during the Civil War between 1861 and 1865. During that war, the first specialized tactical units in communications evolved [Ref. 4:p. 84]. Transmission of military messages during the Civil War was a great factor in stimulating the further development of telegraphy.

Early developments of military telephones began about 1900 due to the great importance of telephone communications in the military. During world War I, other special communications systems including the necessary station equipments were designed for the armed forces. The United States Navy led the way in deploying shipboard systems and means of communicating with captive balloons and airplanes. Developments of special-purpose military communications system were accelerating and the production and installation of such systems were accomplished incredibly fast.

a. Ship-to-ship and Ship-to-shore Communications.

In 1916, about one year before the U.S. entered WWI, the Navy was interested in voice communications between ships at sea and between ships and Headquarters on land. On May 7, Bell Systems demonstrated for the Department of the Navy a long-distance radiotelephone utilizing a special telephone set on the U.S.S. New Hampshire, transmitting equipment at Arlington and receiving equipment at Norfolk, Virginia. This was the first time the two-way telephone had been extended to a vessel at sea [Ref. 5:p. 370].

Short wavelengths were exploited at that time to avoid interference between telegraph and telephone and also to provide a wider range of frequencies to accommodate more telephone channels. As a direct result, the Navy investigated the operation of multiplexing radio-telephone systems with radiotelegraph equipment between the USS Arkansas and USS Florida on 2-1,200 kHz bandwidths at a distance of 30 miles apart. The results were encouraging and led to the design of a multiplexer system with subcarriers at 25, 35, and 45 kHz by R. Heising. After completion of equipment installation on the USS Pennsylvania, USS Seattle, and USS Wyoming in January 1917, the subcarriers were modulated by voice then multiplexed so that nine conversations could be handled at the same time. This was the first practical use of the "carrier" principle [Ref. 5:p. 370].

As the U.S. declared war on April 5, 1917, radiotelephone projects were changed from general to specific military applications. The Navy had requested 15 sets in submarine chasers with short-range communications for the rapid coordination of their movements. These sets were continuous-wave telegraphy with an additional capability of telephone-modulating attachments. Communication between submarine chasers was successful at $4\frac{1}{2}$ miles apart. This equipment became the first radiotelephone equipment standardized by the Navy and it was designated CS-396 with a frequency range of 500 to 1500 kHz and power [illegible] about five watts.

b. Aircraft Communications.

Since the U.S. Army Aviation Services, operated by the Army Signal Corps, and the Navy had perceived the air force to be a striking power at war time, they capitalized on the importance of radio communications between airplanes and ground and airplanes themselves. On May 22, 1917, Western Electric received a request for the development of an airplane set with 2,000-yards range from Chief Signal Officer, General Squire. The development took place rapidly. By August 20, two-way communication between planes in flight was achieved up to two miles apart. The radio set was coded SCR-68 and quantity orders were placed as well as a request for the adaptation of the set to the submarine chasers. Transmission was accomplished by the use of a trailing-wire antenna on the plane with a wind-driven generator placed on the propeller's slipstream. Since tactical flights require high maneuverability, the long trailing-wire antenna was a disadvantage and a modification of design for smaller antenna was greatly desirable. As the design was finalized, the war was coming to an end and there was little, if any, production of the radio sets [Ref. 5:p. 372].

3. The Impact of War on Telecommunications Technology

The developments in radio communications in the early part of the 20th Century had some direct effect on the consequences of WWI. The war had influenced most noticeably military thinking. It led military science into a new era of feasible voice communication among military units in the air, at sea, and on the ground.

Furthermore, wartime efforts substantially affected the telecommunications technology. Due to the nature of doing things very rapidly during wartime, there was little time or effort spent on requirements study and analysis. Consequently, inventions and empirical solutions to technical problems were stimulated by the pressures of necessity. In addition, standardization and quantity production were achieved for equipment and components as a result of wartime programs and experience. Another factor that contributes to the technological advances in the military communication applications is that the cost of providing these facilities was not of major concern.

As telecommunications technology advanced, particularly after WWII, strategic communication for military applications was no longer confined within one country but it had extended across the oceans and the continents. The United States military bases in Europe and Southeast Asia serve as a good example for the intercontinental communications requirement.

Different types of media have been devised and employed such as coax cables, submarine cables, optical fiber cables, microwave networks and satellites. The last one possesses great importance since the beginning of the space age in 1957 due to the fact that the United States and the Soviet Union have competed fiercely to use space for strategic military surveillance and communications. There are at least 273 satellites launched by the U.S.A. for military applications between 1957 and 1970. This makes up 50% of the total satellites orbiting in space [Ref. 4:p. 85].

B. TELECOMMUNICATIONS IN SAUDI ARABIA

In 1970, the Kingdom of Saudi Arabia started employing the five-year planning method for the development of its civilization. In 1975, a second five-year plan was approved in excess of 500 billion riyals ($150 billion U.S. dollars). It was a huge budget due to the kingdom's increasing oil revenues. The objective of this plan was to develop the overall infrastructure of the country.

Telecommunications constitute a fundamental base for every aspect of the present technological world. As a result, Saudi Arabia has capitalized on modern telecommunications systems to assist the development of its infrastructure and, accordingly, telecommunications has become a priority due to several factors. [Ref. 6:p. 2]

The first is religion. Saudi Arabia is in a unique position relative to the Islamic world since it is located at the heart of this world. The second is geography. Saudi Arabia is a large country that contains a diversity of geographical features varying from vast deserts to chains of mountains and terrains. Therefore, its population is scattered over hundreds of towns and villages isolated by long distances. The third is traditions. The society of Saudi Arabia is characterized by strong family ties and the heritage of past generations. These two aspects are strongly developed by the teachings of Islam. The fourth is international presence. Saudi Arabia holds strong relations economically and politically with most of the world as a result of its moderate international policy.

Telecommunications networks in Saudi Arabia can be classified in three categories [Ref. 6:p. 4]:

1. The National Network

This network currently serves more than 400 cities and villages across the country. The plans call for a coverage of 700 cities and villages by 1990. This network is composed of the following:

- **Local Exchange Networks.** Currently there are 1.48 million lines installed using digital exchanges. By 1990, the plan calls for 2.25 million lines to be operational. In addition, 3612 switching circuits are available for international direct dialing to more than 180 countries all over the world. Figure 1 illustrates the growth of local exchange capacity between 1978 and 1987.
- **Automatic Mobile Telephone Network.** There are 20,000 mobile telephone lines via 50 main stations providing subscribers with

normal telephone services and access to the national and international telecommunications networks.

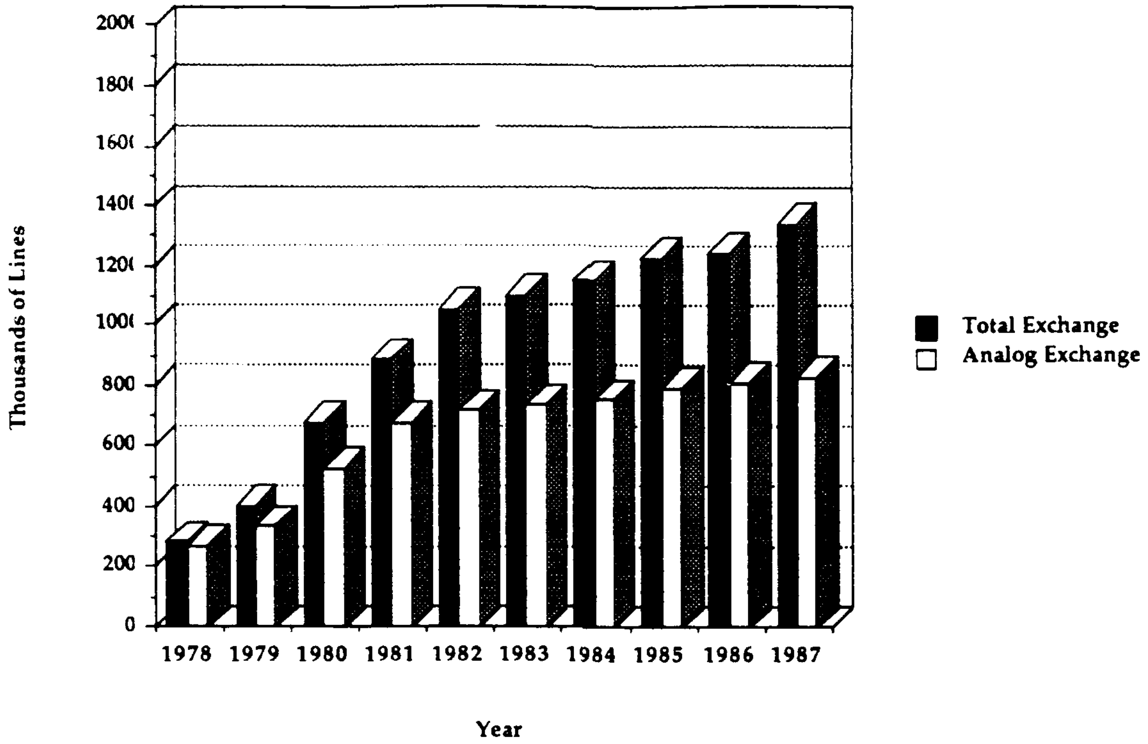


Figure 1-1. Growth of Local Exchange Capacity [Ref. 1:p. 8]

- **Coaxial Cable Network.** There are more than 5000 km. of 12, 18, and 60 MHz coaxial cables that connect the kingdom from east to west and from north to south with a capacity of 27,000 telephone channels and two color TV channels.
- **Microwave Network.** A 20,000 km. microwave system is in place carrying over 75,000 telephone channels and two color TV channels within the country. This network is composed of 450 repeaters and 450 towers.

2. The Regional Network

Due to the common religious and similar cultural background, Saudi Arabia holds unique relationships with its neighboring Arab countries, politically, socially and economically. These ties have been expressed by the implementation of a regional telecommunications network. A satellite system known as ARABSAT was largely funded by Saudi Arabia. An ARABSAT ground station is in place in Jeddah city for communications with the Arab world. Other types of telecommunication systems are summarized in the following table [Ref. 7:p. 1].

TABLE 1-1. REGIONAL TELECOMMUNICAT:ONS

COUNTRY	TYPE OF SYSTEM	CIRCUITS
Bahrain	microwave optical fibre cable	300 1920
Egypt	submarine cable	480
Jordan/Syria	coaxial cable microwave	60 960
Kuwait	coaxial cable microwave	960 960
Qatar	microwave	960
Sudan	microwave (across Red Sea)	960
United Arab Emirates	microwave	960
Yemen	microwave	960

3. The International Network

This network has developed very rapidly during the last decade providing high capacity and a variety of service๑. It consists of satellite, terrestrial, submarine cable, and coastal radio systems. In addition, a huge expansion to the international exchanges has been implemented.

- **Satellite Systems.** A total of six satellite earth stations have been constructed providing more than 10,000 circuits to cover the telecommunication needs of the country to the rest of the world. Five standard A stations communicate with INTELSAT satellites distributed as follows: two in Riyadh, two in Jeddah, one in Taif and the sixth one is an INMARSAT station located in Jeddah for marine and mobile telecommunications.

- **Submarine and Marine Systems.** Saudi Arabia is the major investor in the submarine cable system which extends from Singapore to France via Jeddah with a length of 13,200 km. It owns 1,800 circuits; 916 circuits are already in use among 23 countries [Ref. 8:p. 2].
- **International Exchanges.** Saudi Arabia has seven international exchanges located in Riyadh, Jeddah, and Dammam. Four exchanges are for telephone and the remaining are international telex exchanges. In addition, three packet switching exchanges for data transmission have been recently installed. This network provides more than 10,000 circuits.

The Kingdom of Saudi Arabia also serves as a transit-gateway for international telecommunications due to its geographical location at the center of the world. International telecommunications traffic between East and West goes through the kingdom during off-peak hours [Ref. 7:p. 8].

C. PLANS FOR THE NEAR FUTURE

In the near future, the PTT of Saudi Arabia is planning to establish a modern public data network that consists of three PSN's (packet switching nodes) and 40 packet concentrator locations to cover most of the major population centers. In addition, three international gateways will be installed to support data communications throughout the world.

Furthermore, these future plans set the stage for establishing the necessary ground for introducing the Integrated Services Digital Network (ISDN). Accordingly, PTT is enhancing the current networks for digital operations, expanding the use of optical fiber cable network and installing ISDN-compatible digital facilities. All of these efforts will facilitate the implementation of ISDN enabling subscribers to send voice, data, and images all over the world.

II. COMPUTER COMMUNICATION NETWORKS

A. INTRODUCTION

As technology made its big stride when the industrial revolution started in the 18th Century, rapid development followed in the different fields of mechanical and electrical systems. The steam engine was the predominant technology of the 19th Century.

Although telegraphy and telephony were invented during the 19th Century, they also served as the bridge into the 20th Century. This century can be characterized as the information technology age. On the other hand, computer networking has changed dramatically just in the past 15 years to accommodate the growing needs of the information and communications technologies. Therefore, sharing resources such as databases, application programs, and all different types of hardware is the primary objective of such computer networks.

B. NETWORKING

The term network can be defined as the linking of groups of computers so that they can communicate with each other and share resources. The linking of computers can be implemented within an organization to connect individuals or among several organizations.

Local area network (LAN) defines the configuration of a network within a centralized organization whereas long-haul networks, known as Wide Area Networks (WANs), typically cover users in different organizations spread over entire countries [Ref. 9:p. 3].

A third category of networks, known as Metropolitan Area Networks (MAN), defines a network that is between the LAN and the WAN. A MAN network covers an area of an entire city using LAN technology. This was used at the beginning of cable television but it is widely used to connect computers within one city [Ref. 10:p. 117]. This section will focus on WAN networks, their structure, and their architecture.

1. Computer Network Structure

In general, a wide area network consists of the following:

(1) The users
(2) The access facility (the access network)
(3) The backbone network (the subnet)

The term user here is defined to be any entity that uses the network to communicate with another entity. Examples of such users are terminals, mainframe computers, and end-users. The term **host** has been widely used to designate the user portion of the network.

The access network is defined as the area of the network that facilitates a user's access (a host) into the subnet or the backbone in order to establish connection across the *whole* network to another host. Components of such an access network are the terminal access contollers (TAC) that allow terminals to access the backbone. Network access components (NAC) is a mini-TAC part of the access network and is a protocol translation device that supports asynchronous devices and the IBM 3270 [Ref. 11:p. 30]. Gateways and bridges fall into the access network area as well.

The third part of a computer network structure is the backbone network. This is the heart of the network and it is sometimes referred to as the communicatio subnet. Its primary function is to carry messages from host to host. It consists of two distinct components: 1) transmissions lines, 2) switching elements.

The function of the transmission lines, sometimes called circuits, trunks, or channels, is to move data bits between machines. Switching elements are special-purpose minicomputers used to connect two or more transmission lines. When data arrive on the incoming lines, this minicomputer decides on which output line to send them [Ref. 10:p. 6]. Figure 2-1 depicts the general structure of a network.

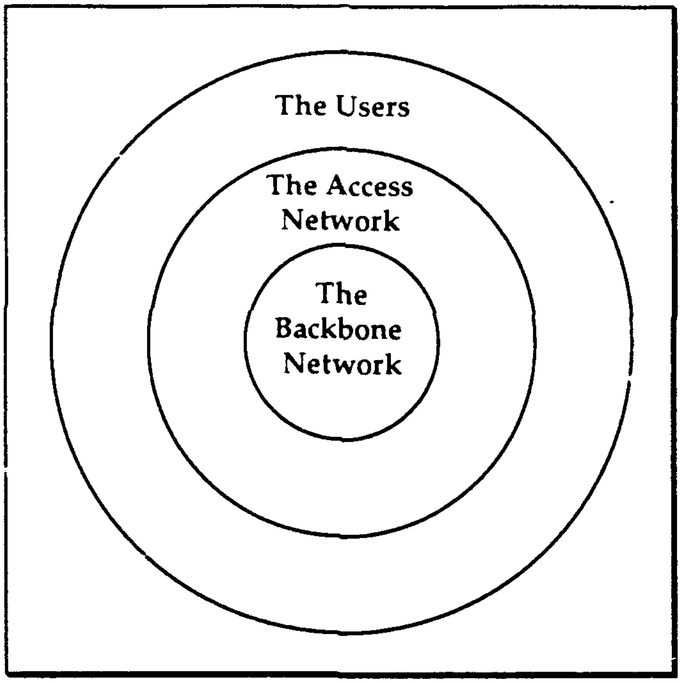


Figure 2-1. The General Structure of a Network

The communication backbone has two types of design: point-to-point and broadcast. In a point-to-point network (often called switched network) communication is established between the source host and the destination host through a series of switching elements (nodes). In broadcast networks a single communication medium is shared by all users on the network. When a message is transmitted by any machine, it is received by other machines on the network and the intended destination machine is specified by means of an address field within the message [Ref. 10:p. 7].

2. Computer Network Architecture

a. Definitions

A network architecture is defined to be the formation of a structure. It describes what components or elements exist, how they operate, and what form they take. This generally includes hardware, software, communications link control, topologies and protocols [Ref. 1:p. 270].

A protocol is a set of rules and conventions that govern the establishment of communications, the exchange of data, and the termination of communications between entities in different systems. An entity is any object with a capability of sending or receiving information such as a user application program, electronic mail, and file transfer packages. On the other hand, a system is a physically distinct object with one or more entities existing within it. Examples of systems are computers and terminals [Ref. 12:p. 20]

It should be noted that hardware in the field of computer communication networks (CCN) is fairly standardized for telecommunications. On the contrary, software is extremely complex. Therefore, most networks are built using a layered approach to reduce the design complexity of the communications protocols. Each layer or level in the hierarchy performs certain functions to provide services to the next higher layer. Accordingly, each layer is designated a protocol that communicates with the corresponding layers on the different systems of the network. Entities within these corresponding layers are called peer processes [Ref. 10]. Figure 2-2 depicts this relation.

b. The OSI References Model

It is a major requirements of access networks to communicate using the available heterogeneous system. Protocols must be standardized to avoid the uniqueness of each vendor's products in communicating with different machines. This fact led the International Standards organization (ISO) to develop a set of guidelines for obtaining standards in linking heterogeneous computers. In 1983, ISO adopted the open systems interconnection (OSI) reference model. That is to say that any two systems conforming to the OSI standards can openly communicate with each other.

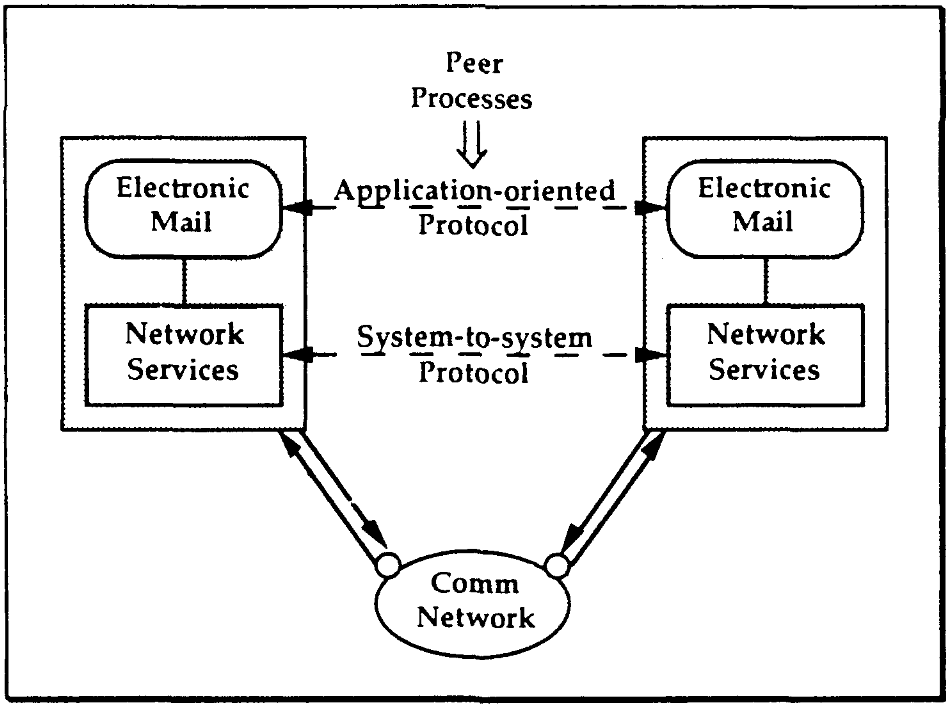


Figure 2-2. Peer Processes in a Network

The OSI reference model consists of seven layers numbered sequentially from the lowest layer to the highest. Each layer is defined by the services offered to the next higher layer. A brief summary of each layer follows [Ref. 1, 10, 12]:

(1) The physical layer. This layer is the lowest in the hierarchy of the OSI model. It deals with the transmission of unstructured raw bits over the physical medium.

(2) The data risk layer. This layer is responsible for the transfer of data over the channel. It also provides for synchronization, identity of data, error detection, and flow control.

(3) The network layer. This is the layer where the control of routing messages in the subnet (backbone) takes place in a transparent manner between the transport entities.

(4) The transport layer. This is the layer responsible for the exchange of data between processes in different systems in a sequential pattern with no loss, error, or duplication. It is also responsible for splitting up the data into smaller units if needed.

(5) The session layer. It serves as user interface to establish communication session between entities on different machines. It also provides mechanisms for retransmission if a failure occurs.

(6) The presentation layer. Its function is to provide for the syntax of data exchanged between entities. It usually contains tables of syntax in ASCII, EBCDIC and Videotex. An example of a layer six protocol is the virtual terminal protocol.

(7) The application layer. This layer provides facilities to support the end-user application processes. It generally consists of mechanisms to support management functions for distributed applications. Such protocols are file transfer and electronic mail. Figure 2-3 illustrates the layers of the OSI reference model.

C. SWITCHING TECHNOLOGIES

A communication between two devices can be established by direct connection. But a problem exists if the number of devices increases. The number of links is related to the number of devices N as follows:

# of full-duplex links = N(N−1)/2.

So, if there are ten devices, then 45 full-duplex links are required. Obviously, it is impractical and it is not cost-effective. As a result, a communication network is the appropriate approach to resolve the problem [Ref. 12:p. 194].

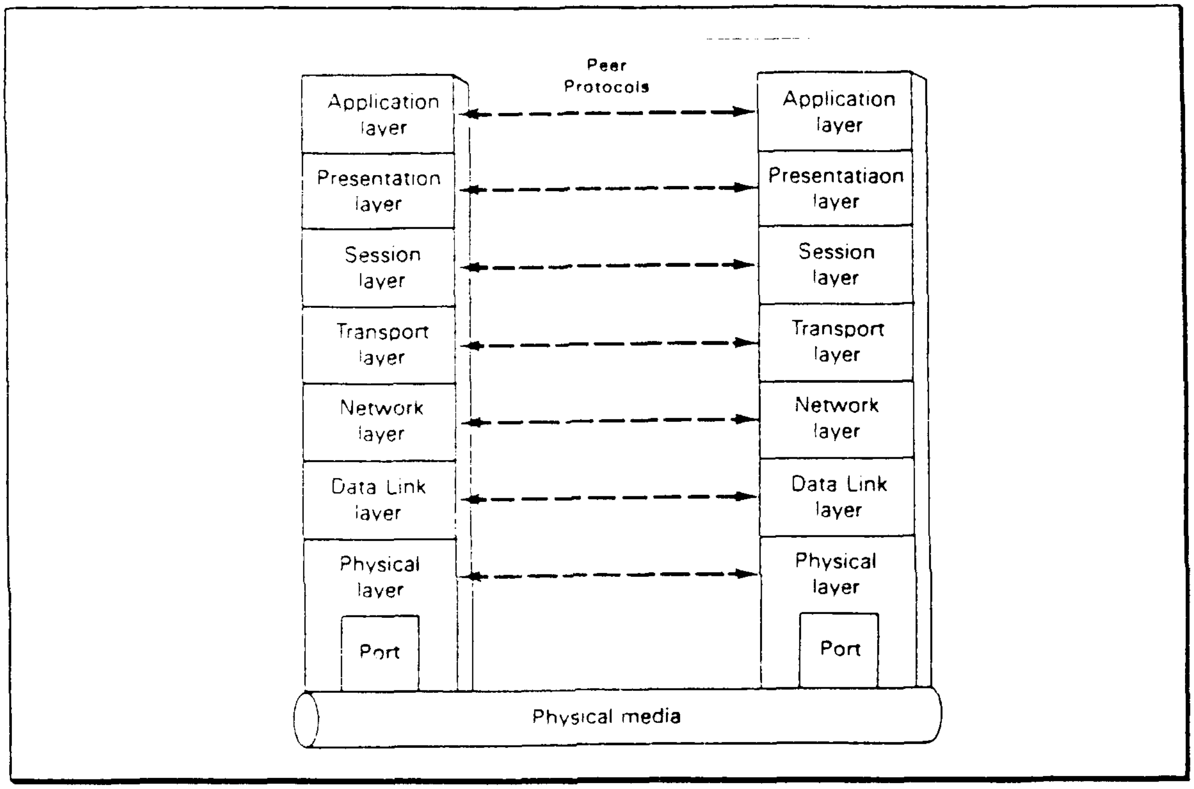


Figure 2-3. The OSI Layers

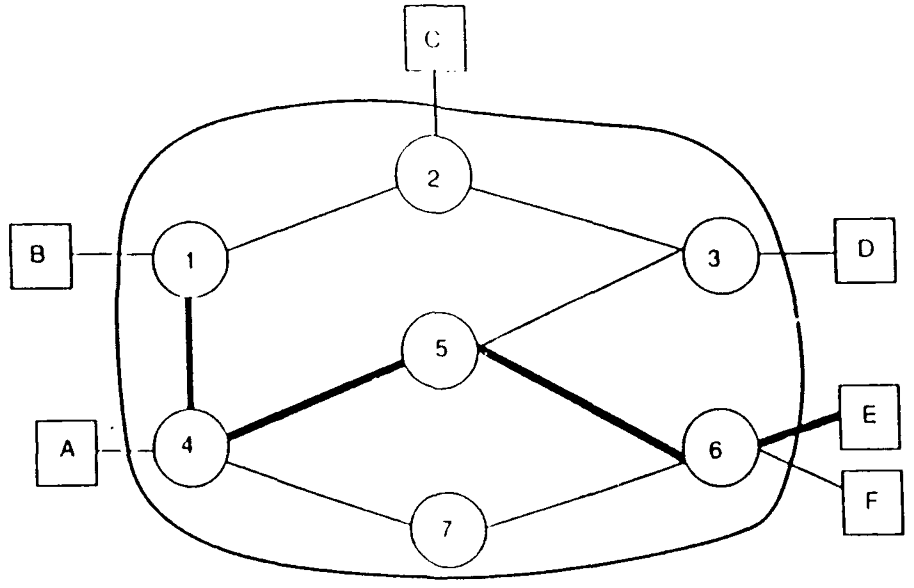
Three widely used switching techniques are employed in the switched networks (point-to-point networks). They are circuit switching, message switching, and packet switching.

1. Circuit Switching

In circuit switching, a connection path is dedicated between two stations via a sequence of links among nodes (switching elements). The process of communication using this technique involves three stages. The first stage is circuit establishment where the setup of a dedicated physical path from source to destination takes place.

The second stage is data transfer where all the information travels along the physical route which was set up during the first stage. The third stage is circuit disconnect. At this point, all circuits along the path are freed.

Circuit switching is the oldest technique and it is commonly used by the public telephone companies. Figure 2-4 shows how circuit switching works [Ref. 13:p. 26].



Call Connecting B to E

Note that A cannot call B, C, D or E until call is terminated

Figure 2-4. Circuit Switching

2. Message Switching

Message switching was the first type of switching tailored specifically for computer communication networks. It is often called store-and-forward switching. As a message leaves its source machine, it is stored in the first switching node and then it is forwarded to the next node along the path until it reaches its destination.

A message is delayed at each node for the time required to receive all bits of the message, to check for errors, and then to retransmit. Consequently, this switching technology is used when time is not a critical factor since transmission delays along the path can be significant. The routing of the message can be static or dynamic as the message travels towards its destination. Figure 2-5 depicts message switching [Ref. 13:p. 27].

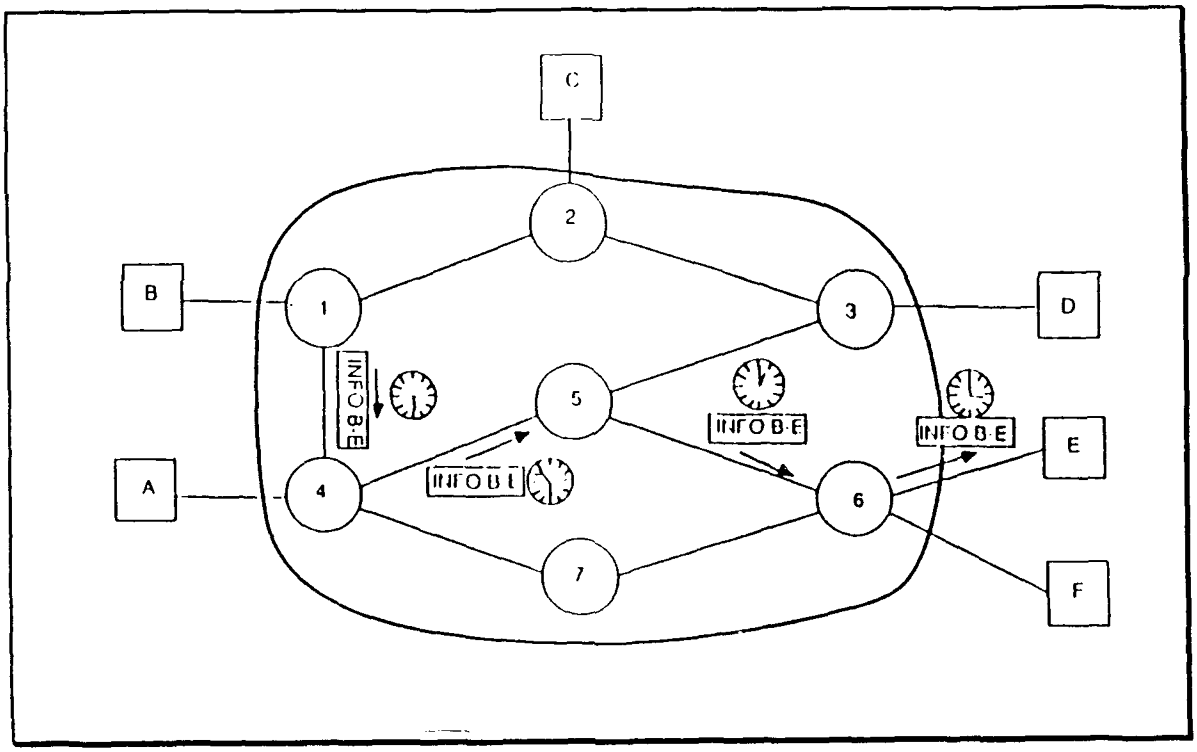


Figure 2-5. Message Switching

3. Packet Switching

Packet switching is similar to message switching except that packet switching networks place a right upper limit on the block size with a maximum length of 1000 to a few thousand bits. Therefore, messages above the maximum length are broken into smaller units called packets.

At the source machine, addressing information is attached to the packet, and packets are sent to the local switch for transmission to another node in the network. At each node, the packet is held in a buffer for error control, and for previously received packets to be transmitted.

Packets belonging to a message (i.e., one large file to be transferred) can take different routes. At the destination node, these packets are arranged in the original sequence before deliver'-g to the destination host. Packet switching is depicted in Figure 2-6 [Refs. 13, 14].

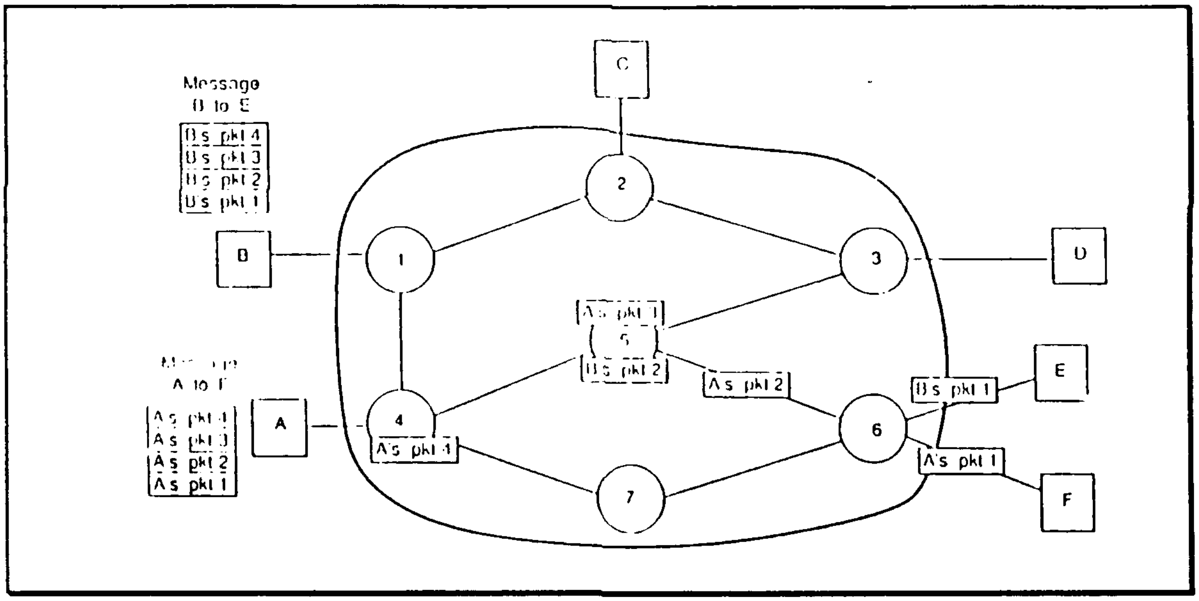


Figure 2-6. Packet Switching

D. TRANSMISSION MEDIA

A transmission media is the physical path which the physical layer uses to transfer a raw bit stream from a transmitter to a receiver. Transmission media fall into two broad categories: hardwire (twisted pair, coaxial cable, and optical film cable) or softwire (air, vacuum, and seawater) [Ref. 13:p. 17].

In this section, the most commonly used media will be briefly discussed.

1. Twisted Pair

It is the oldest and still most common transmission media. It consists of two insulated copper wires, typically about 1 mm thick, twisted together in a helical pattern in order to reduce electrical interference. Telephone companies are the primary user of it.

Twisted pair can be used for digital and analog transmission. It is widely used in local networks due to its low cost, availability, and ease of use. However, twisted pair is limited in distance, bandwidth and data rate capability [Ref. 10:p. 58].

2. Coaxial Cable

A coaxial cable consists of a stiff copper wire as the core, surrounded by an insulating material. On top of that, a cylindrical conductor in the form of a braided mesh is covered in a protective plastic sheath.

Two kinds of coax cable are widely used for analog and digital transmission. One kind, 50-ohm cable, usually termed **baseband cable**, is used for digital transmission. A data rate of 10 Mbps is feasible with a length of one kilometer.

The other kind is the 75-ohm Community Antenna Television (CATV) sometimes called **broad band** used for analog transmission. In computer networks using broadband, an interface is needed to convert the outgoing digital bit stream to an analog signal, and the incoming analog signal to a bit steam [Ref. 10:p. 59].

3. Optical Fiber

Optical fiber is a thin (50 to 100 micrometer) medium capable of transmitting data by pulses of light. Optical fiber is made of various glasses and plastics. Optical fiber is used extensively for long-distance telecommunications and military applications [Ref. 13:p. 19].

There are several advantages to using optical fiber as a transmission medium. Fiber optics cable is small in size and lighter in weight. Data rate in the giga bps is feasible over long distance. Another advantage is the signal loss due to attenuation is much lower than in other media. In addition, optical fiber systems are immune against noise and interference [Ref. 15:p. 585].

4. Terrestrial Microwave

For long-distance communication, microwave transmission is commonly used. Parabolic antennas are mounted on towers to send a beam to another antenna which is in a line of sight to the sending antenna. Microwave is an alternative to coaxial cable for transmitting television and voice.

Lately, microwave has been widely used for short point-to-point links between buildings. This can be used for closed-circuit TV or as a data link between local networks. Moreover, terrestrial microwave has the potential for transmitting digital data in small regions (radius < 10 km). This concept has been termed "local data distribution," and would provide an alternative to phone lines for digital networks [Ref. 12:p. 57].

5. Communication Satellites

A communications satellite is simply a microwave relay station located in a constant orbit above the Earth's atmosphere. It is used to link two or more ground-based microwave transmittal receivers, known as earth stations or ground stations [Ref. 12:p. 59].

The satellite operates on two different frequencies. One frequency, called the up-link, is used to receive transmission from the ground stations. It amplifies (analog transmission) or repeats (digital transmission) the signal. Then, it transmits on the second frequency, which is called down-link.

For a communication satellite to be effective, it must be at an altitude of approximately 36,000 km above the equator in order to have a period of rotation equal to the Earth's period of rotation (24 hours).

Communication satellites are being used for international telephone trunks, telex, and television over long distances. It is considered to be the optimal medium for high-usage international traffic and is competitive with line-of-sight microwave and coaxial cable for many applications [Ref. 12:p. 60].

III. U.S. DEFENSE DATA NETWORK

A. INTRODUCTION

The United States Defense Data Network (DDN) has been designed to meet the U.S. Department of Defense (DoD) requirements for a secure, reliable, and efficient computer communication network. It allows communication of a variety of user applications ranging from logistics to the most critical intelligence data transmitted among mainframe systems of various security levels.

The commitment to DDN to be the common-user world-wide data communication network is the result of the directive issued by the Secretary of Defense in March 1983. The policy states

> All DoD Automatic Data Processing (ADP) systems and data networks requiring data communications services will be provided long haul and area communications, interconnectivity, and the capacity for interoperability by the DDN. Existing systems, systems being expanded and upgraded, and new ADP systems or data networks will become DDN subscribers [Ref. 21:p. 2].

B. DDN HISTORY

In the early 1960s, the development of the message switching systems, known as Automatic Digital Network I (AUTODIN I) was begun to provide common-user automated data communication. AUTODIN I was considered a major advance in digital communications and it set the stage for the later development of the DDN [Ref. 18:p. 121].

The Defense Advanced Research Projects Agency initiated the first packet-switching network project, known as ARPANET, in 1969. The project was designed as an intra-agency communications system and as an experiment investigating new technologies. The research team desired to expand the network functions across the continent of the United States as the need to share information and to access remote databases grew rapidly [Ref. 9:p. 5].

As the research community proved that users of different types of computers could share programs and communicate over long distances, ARPANET allowed participation of users with operational requirements. As the number of operational users of the network increased, the responsibility for its operation was transferred to the Defense Communications Agency (DCA) in 1975 [Ref. 21:p. 3].

During that time period, plans to replace AUTODIN I by AUTODIN II were developed to employ packet-switching technology. Those plans were driven by the fact that the DoD requirements for a highly secured military communications network became inevitable. Moreover, the increased common carrier costs for long distance leased lines were economically unjustifiable due to the inherent limitations of AUTODIN I.

In September 1981, DCA initiated a study comparing the planned AUTODIN II to ARPANET. The study revealed that it was no longer beneficial to support the development of two packet-switched networks. Therefore, the ARPANET technology was chosen over AUTODIN II to be the basis for the development of the national DDN. The DDN project was started and the AUTODIN II was canceled, in April 1982, based on risk assessment, cost, and ւxpandability [Ref. 9:p. 5].

C. DDN STRUCTURE

The DDN is a large military common-user data communications internetwork. It is designed to support military operations and critical intelligence systems as well as general purpose automated data processing (ADP) systems. Moreover, it supports distributed applications with long-haul data communications requirements.

The U.S. DDN consists of several networks. These networks have compatible hardware and software which allows them to communicate with each other. In this section, the DDN segments and components will be looked at in order to achieve the overall picture of the network.

1. The DDN Segments

In reality, the DDN is composed of a family of network segments. Each segment is a network in its own right that operates independently at its own security level. Communication gateways exist between unclassified networks. But at higher levels of classification, the physical separation of the networks has been preserved to enhance security [Ref. 18:p. 121].

The major segments of the DDN serve different types of users in the DoD community. The MILNET, a military operational network, and the ARPANET, a military research and development network, constitute the unclassified segments of the DDN. The classified segments of the Defense Data Network consists of several independent networks. These include the Strategic Air Command Digital Information Network (SACDIN), the Defense Integrated Secure Network (DISNET), now called Defense Secure Network One (DSNET 1), the Secure Compartmented Information Network (SCINET), now called DSNET 3, and the World Wide Military Command and Control

System (WWMCCS) Intercomputer Network (WIN), now called DSNET 2 [Ref. 21:p. 19].

The evolution of the U.S. DDN progressed in distinct stages since 1982 to reach the mature configuration. The final configuration of the DDN will be of a single, multi-level secure communication network. The integrated DDN depicted in Figure 3-1 will be achieved by the implementation and use of the Blacker technology. This technology, available in the early 1990s, will allow the separate classified subnetworks to merge into a single, shared, secure network, and will more readily support multi-level secure computer systems [Ref. 21:p. 12].

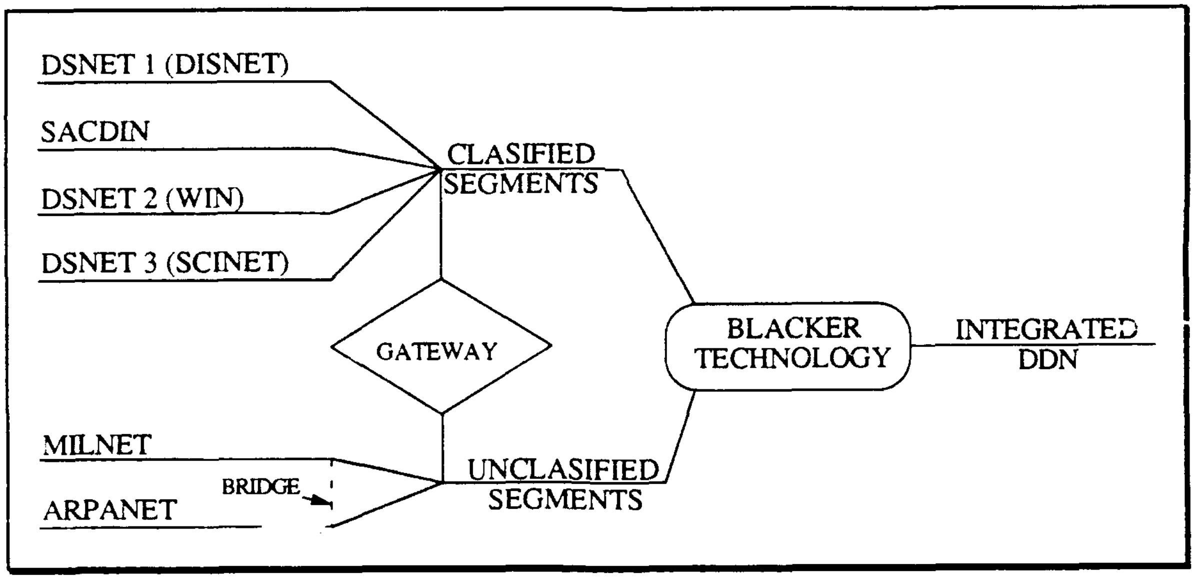


Figure 3-1. Evolution of the Integrated DDN

2. The DDN Components

The Defense Data Network uses packet-switching technology in its components. Three major components make up the DDN:

a. *Packet-switching nodes (PSNs)*

PSNs, which link together the network trunk lines to route data packets between source and destination, compose the DDN backbone. The PSNs offer reliable and efficient transmission of data throughout the network. The packet switch used in the DDN is a Bolt Beranek, and Newman C/30E computer. It can serve as a point of entry, a relay, or a point of exit for the DDN backbone.

The DDN backbone consists of hundreds of packet switches located throughout the world. Most of the transmission links, within the U.S.A., consist of digital leased terrestrial circuits operating at 56,000 bits per second (bps). In addition, other transmission requirements for other speed lines are available such as 9,600 bps and 64,000 bps. Outside the United States, transmission links vary in speed depending upon service availability [Ref. 21:p. 4].

The PSN software includes a distributed, dynamic adaptive routing algorithm which enables the nodes to cooperate automatically in routing traffic around congested or failed switches and trunks. At a node, each incoming packet is time-stamped with an arrival time. A departure time is recorded when the packet is transmitted. If a positive acknowledgement is returned from the next node, the delay for that packet is recorded as the departure time minus the arrival time plus transmission time and propagation delay.

Therefore, the node must know link data rate and propagation time. If a negative acknowledgement is returned from the next node, the departure time is updated and the node tries again until a measure of successful transmission is achieved. The node computes the average delay every ten seconds and updates its routing table. This adaptive algorithm has proved to be responsive and reliable in the case oí individual nodes and for trunk line failures [Ref. 12:p. 271].

b. *DDN Network Access*

The access network of the DDN encompasses a variety of computer and terminal connections. Three configurations are widely used to connect mainframe computers.

First, in the direct method, where a host computer connects directly to a PSN. Although it is not an efficient way of using a switching node access port, the user does not depend on any other access equipment to reach the DDN backbone.

The second configuration uses the Host Front End Processor (HFEP) between one or more hosts and a PSN. This processor converts all incoming data from the hosts into formats acceptable for DDN transmissions. HFEP performs the networking functions and frees the host computer for data processing. This is in contrast with the direct method where the host performs the networking functions.

The third configuration uses a Terminal Emulation Processor (TEP). This processor allows terminals to access their remote hosts through the network instead of via a dedicated line to the host [Ref. 9:p. 27]. Its examples include TACs and NACs, which are described below.

Terminals which are not attached to a mainframe system can access DDN by the use of Terminal Access Controller (TAC). Each TAC consolidates the input of 63 asynchronous terminals into one line that connects to the PSN. TACs add more security to the network by requiring user identification. The Network Access Controller (NAC) mini-Tac is another network access component that allows 16 ports of synchronous and asynchronous terminal connections.

Personal computers/systems (PC/PS) that can perform mainframe systems type functions can be attached directly to a PSN port but that is not efficient since networking functions will be done by the personal computer/systems thereby wasting resources greatly needed for data processing. A more cos effective and efficient way of accessing DDN is to have a number of PCs/PSs on a LAN configuration via a gateway. A gateway is a device that allows communications among heterogeneous networks and does the networking functions, thus freeing the PC's/PS's processing resources. Figure 3-2 illustrates the DDN components.

The transmission speeds of access network circuits are 9,600 to 56,000 bps. The TACs maximum transmission rate is 9,600 bps. The maximum transmission rates for the NACs are 9,600 bps asynchronous and 19,200 bps synchronous [Ref. 21:p. 16]. The Defense Communication Agency (DCA) has deployed a device called Very Small Aperture Terminal (VSAT), that allows high transmission rates over long distances. VSATs use a government satellite to transmit and receive information at a rate of 56,000 bits per second [Ref. 15:p. 29].

c. *The Network Monitoring Center (NMC)*

An NMC is used to provide control, monitoring, and management functions for the DDN. Currently, there are regional monitoring centers in Europe, the Pacific and the Continental United States for the MILNET. In addition, there is an NMC for every other separate segment of DDN.

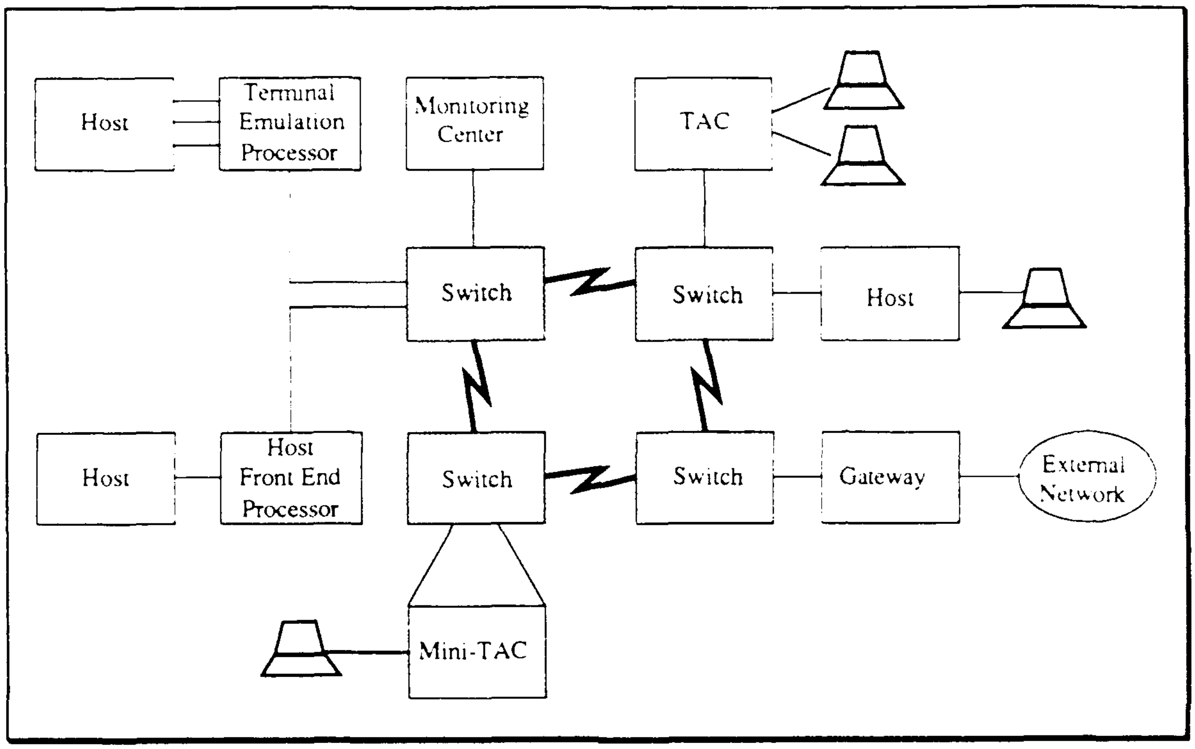


Figure 3-2. DDN Components

Each NMC contains a minicomputer with special applications software. It provides fault detection and isolation, remote configuration of PSNs, TACs and NACs, real-time monitoring and capacity planning, usage accounting, and management reporting.

The NMC is not critical to the movement of data packets throughout the network. Packet routing and congestion control are completely independent of central network resources and can proceed even in the event of temporary NMC failure [Refs. 18, 121].

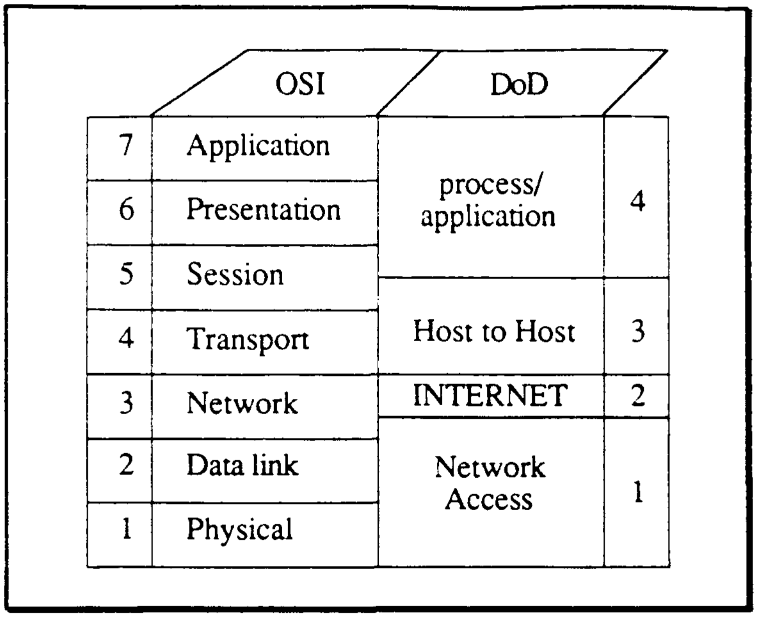
D. THE DDN ARCHITECTURE

The U.S. Department of Defense (DoD) has set military computer communication standard protocols as a direct result ot two factors. The first is the rapid proliferation of computers and other signal processing elements throughout the military and the requirement for the use of multiple vendors. The second factor is the rapid proliferation of communication networks throughout the military and the need for a variety of networking technologies.

The DDN communications architecture is based on the U.S. DoD communications architecture. The DoD protocols and standards were specified and used prior to the completion of the OSI reference model development by ISO. Furthermore, DoD specific requirements for security and robustness were not reflected well in the OSI model. Therefore, knowing that DoD's need was immediate, it was decided not to wait for the ISO protocols to evolve and to stabilize. Figure 3-3 presents a comparison of the OSI reference model and the DoD communications architecture [Ref. 16:p. 2,21].

1. DoD Communication Architecture

The Defense Communications Agency (DCA) based DoD architecture on three parts: processes, mainframe systems (hosts), and networks. Therefore, the transfer of information to a process is carried out by first getting to the host where the process resides and then executing the process within that host. A network is then concerned with routing data between hosts as long as the rules (protocols) governing how to direct data to processes are clearly established.



	OSI	DoD	
7	Application	process/ application	4
6	Presentation		
5	Session		
4	Transport	Host to Host	3
3	Network	INTERNET	2
2	Data link	Network Access	1
1	Physical		

Figure 3-3. A Comparison between the OSI Model and DoD Communications Architecture

Keeping in mind the importance of the hierarchical ordering of protocols, the DoD communications architecture is organized into four layers as shown in Figure 3-3.

(1) The network access layer. This layer provides access to the communications network. The main functions of protocols at this layer, which are between a PSN and an attached host or its logical equivalent, are routing data, flow control and error control between mainframe systems and other quality of service functions such as priority and security.

(2) The internet layer. A protocol at this layer is usually implemented on hosts and gateways to allow data to traverse several networks between computers. The primary function of a gateway is to relay and transfer data between networks using an internetwork protocol.

(3) The host-to-host layer. At this level, the major function is to deliver data between two processes on different host computers reliably. As entities in this layer are invoked, they may (or may not) provide a logical connection between higher entities. Other functions of this host-to-host layer include error and flow control and the ability to deal with control signals not associated with a logical data connection. [Ref. 20:p. 29]

(4) The process/application layer. In this layer, protocols, that facilita'e resource sharing such as computer-to-computer and remote access such as terminal-to-computer, reside.

In accordance with this architecture, DoD, through DCA, has issued a set of military protocol standards. Th·se military standard protocols are defined briefly in Table 3-1 [Ref. 20].

TABLE 3-1. DOD MILITARY STANDARD PROTOCOLS

MIL-STD-1777 Internet Protocol (IP)	Provides the capability for end systems to communicate across one or more networks. Does not depend on the network to be reliable
MI-STD-1778 Transmission Control Protocol (TCP)	A reliable end-to-end data transfer service equivalent to the OSI reference model layer 4, transport protocol
MIL-STD-1780 File Transfer Protocol (FTP)	A simple application for transfer of ASCII, EBCIDC, and binary files
MIL-STD-1781 Simple Mail Transfer Protocol (SMTP)	A simple electronic mail facility
MIL-STD-1782 TELNET Protocol	Provides simple asynchronous terminal capability

2. The DDN Configuration

As mentioned previously, "interoperability" is the major objective set forth in the defense community. However, interoperability has become one of the most vital ιechnical requirements so that internetworking capabilities must be supported in a largely mixed-network environment, thus requiring several gateways, like the DDN. Since the same protocols are implemented on all data processing equipments of all DDN subscribers, interoperability is achieved for the functions and services provided by those protocols. The general DDN protocol configuration is illustrated in Figure 3-4 [Ref. 1:p. 290].

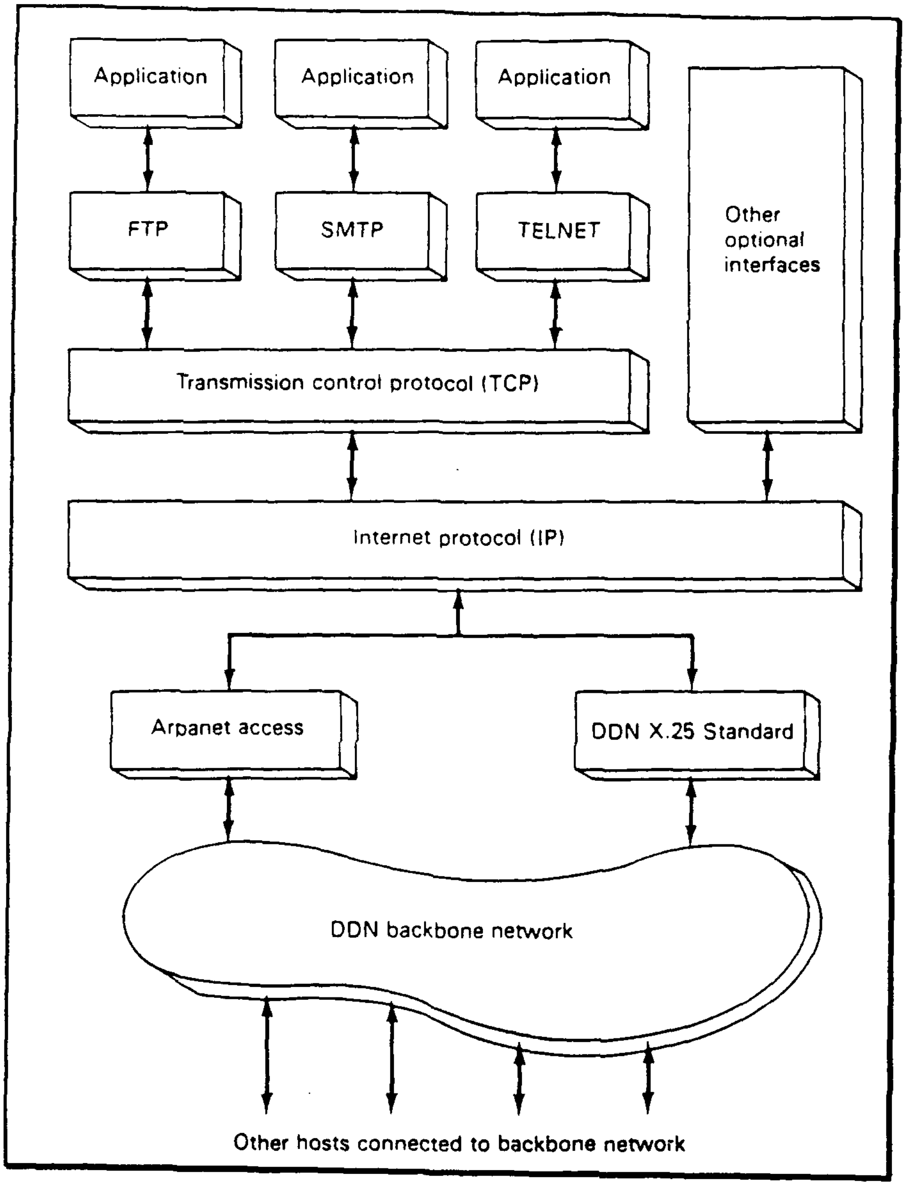


Figure 3-4. Defense Data Network (DDN)

a. Protocol Mechanisms

The key protocol mechanisms involve four functions: Segmentation and preassembly, encapsulation, connection control, and addressing [Ref. 12:p. 380]. These functions facilitate the exchange of streams of data between two entities.

The segmentation function can be defined as the process of breaking up data into blocks of smaller bounded size. These blocks of data are referred to as Protocol Data Units (PDU). The DDN may only accept packets up to a maximum size of 1024 bytes. This results in a more efficient error control and more equitable access to shared transmission media.

The segmentation function can occur at any of three layers of the architecture below the process/application layer. As the network access layer receives a PDU from the internet layer, the network access, protocol splits the internet datagram into a number of parts and places a packet header on each one. These packets will be reassembled, the counterpart of the segmentation function, into a single internet datagram by the destination network protocol for delivery to its internet protocols.

Encapsulation is the addition of control information to data. Each PDU contains data plus control information and some PDUs contain only control information. As each PDU traverses through the layers, a header that contains control information is added (encapsulated) to it. This becomes the user data unit to the lower layers. Finally, the full PDU is transmitted.

At the destination host, a PDU arrives coming up through the layers in the reverse order. The header that was added by the peer entity (within the peer layer) at the source host is stripped off (decapsulated) by the peer entity at the destination host. Functionally, the control information contained in the header is instrumental in invoking the functions across the network to the peer layer. In addition, control information may include the address of the sender and/or receiver and error detecting code. Figure 3-5 shows the encapsulation and decapsulation process [Ref. 1:p. 284].

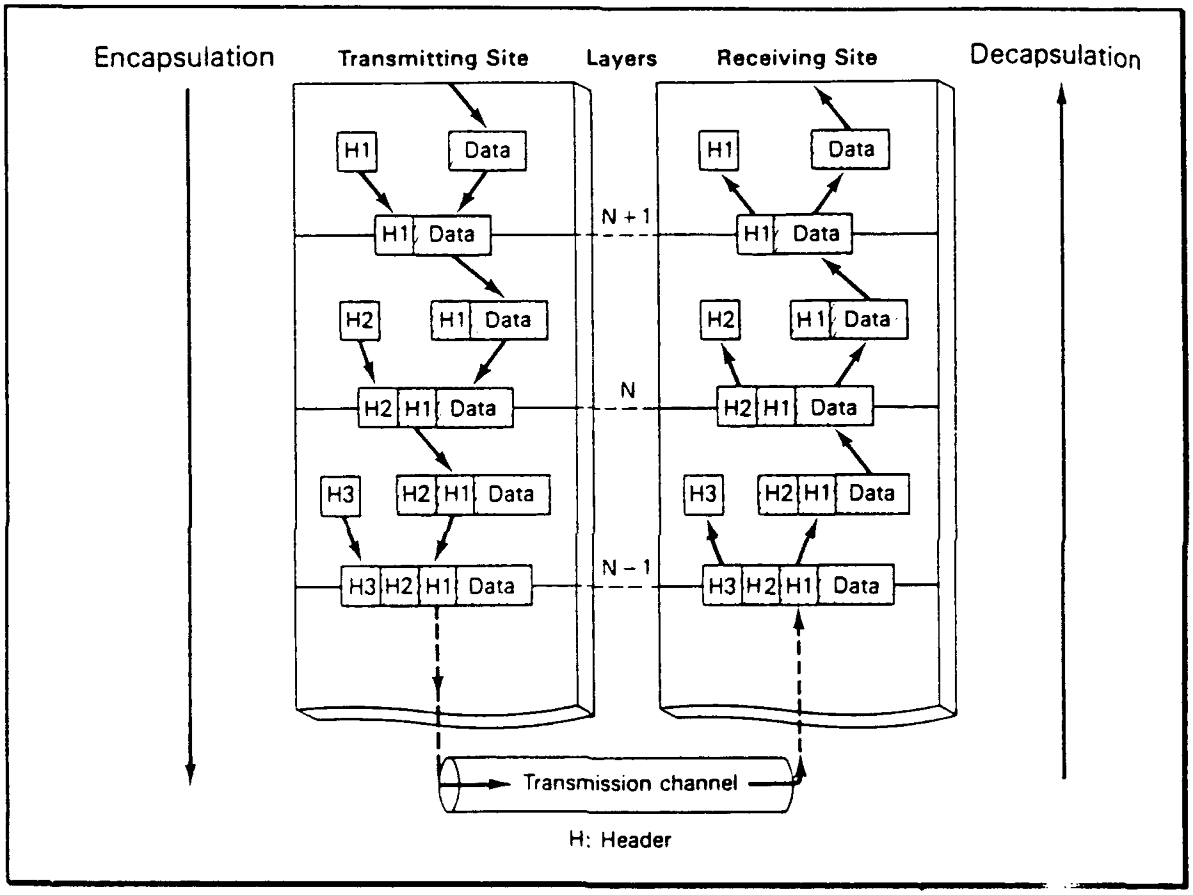


Figure 3-5. Encapsulation and Decapsulation Process

Connection control normally takes on two forms for data transfer. If an entity may transmit data to another entity in an unplanned fashion and without prior coordination, this service is known as connectionless data transfer. The IP within DDN uses this kind of service in order to provide a wider range of internetworking capability.

The second form is known as the connection-oriented service. It involves a logical association (connection) between the communicating entities in three phases: connection establishment, data transfer, and connection termination (see Figure 3-6). In DDN, TCP is connection-oriented protocol to support reliable data transfer. Since FTP, SMTP, and TELNET use TCP, they are connection-oriented as well. Figure 3-5 illustrates the steps involved in connection-oriented service [Ref. 12:p. 382].

Addressing is the means for two processes to uniquely identify each other. DDN supports an environment of multiple networks, multiple hosts on each network, and multiple processes/applications in each host. Therefore, DDN maintains a complex addressing scheme.

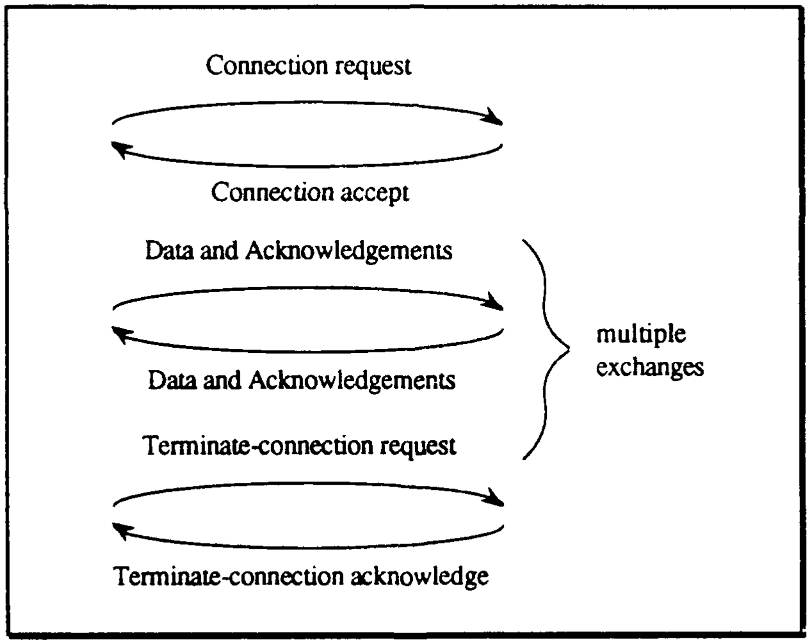

Connection request
Connection accept
Data and Acknowledgements
Data and Acknowledgements
multiple exchanges
Terminate-connection request
Terminate-connection acknowledge

Figure 3-6. The Phases of a Connection-oriented Service

Each network must have a unique address for each host on that network. The address is known as the subnetwork attachment point address. The IP has the responsibility to deliver datagrams across multiple networks from source to destination. Consequently, the IP is provided with a global network address that uniquely identifies each host. Furthermore, a host may have more than one link into the same network. Accordingly, the host address has a global significance while the subnetwork attachment point address has significance within a network. So, the IP must translate from the global address to the local address of the host to transmit data across the network.

Finally, a data unit is delivered to a host through the host-to-host layer for delivery to the ultimate user (process). Since there may be several users, each is given a port number that is unique within the host. The combination of port and global network address uniquely identifies a process within DDN. The following host address: 26.3.0.16, for example, identifies the host to be on MILNET since 26 is the MILNET network number [Ref. 14]. It occupies port 3 on PSN 16. Figure 3-7 illustrates the addressing scheme as related to DDN.

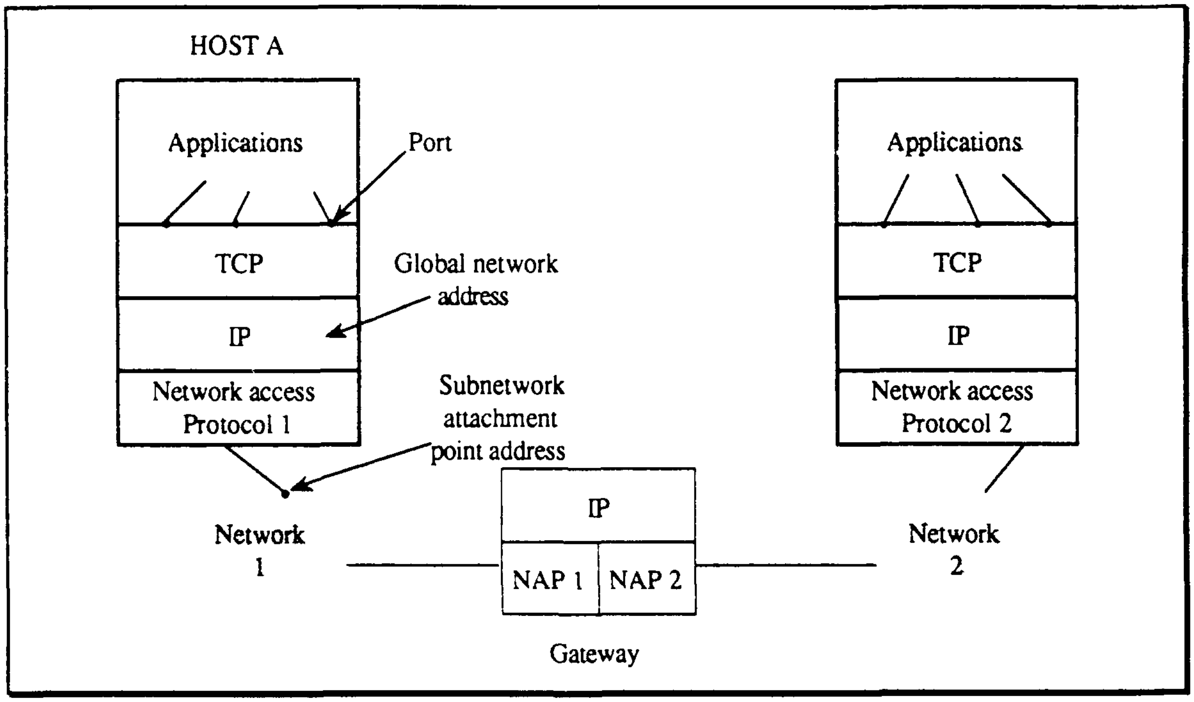


Figure 3-7. The DDN Addressing Scheme

b. The Network Access Protocol (NAP)

The network access protocol defines the interface between the host computer, called DTE (Data Terminal Equipment) by CCITT, and the network to which it is attached, called carrier's equipment CDE (Data Circuit-terminating Equipment) by CCITT [Ref. 11].

Host computers can access the DDN using either CCITT X.25 protocol, the DDN standard protocol, or the old ARPANET Host Interface Protocol (AHIP). These protocols can be supported on a PSN with full interoperability. Computers supp ting these protocols can be attached directly to a DDN node. Hosts on other networks, such as local area networks, can use a X.25 gateway to obtain DDN access [Ref. 18:p. 122].

c. The Internet Protocol (IP)

The primary function of the IP is to interconnect all the network segments under DDN and other networks so that any two users on any of the constituent networks can communicate. Each segment of the DDN supports communication among a number of attached devices. Additionally, networks are connected by gateways providing a path for data exchange between networks [Ref. 16].

As illustrated in Figure 3-7, IP is implemented in each endpoint computer and in each gateway within the DDN. IP provides unreliable connectionless service meaning that some PDUs may never reach its intended destination or those that do may get there out of sequence. In this situation, the TCP functions to assure reliable data transfer.

If two computers, A and B, on two different networks wish to communicate, the operation of IP can be described as follows. The module in host A builds a PDU that contains data from TCP and an IP header of control information used by IP. The PDU is sent across A's network to the appropriate gateway. As the PDU arrives at the gateway, it must make a routing decision. If host B is directly attached to one of the networks to which the gateway is attached, the IP module in the gateway sends the PDU across that network.

On the other hand, if more additional gateways must be traversed, the PDU is sent across a network to the next gateway on the proper route. This situation is known as multiple-hop situation. Thus, the IP module in each host and gateway must maintain a routing table that give for each possible destination network, the next gateway on the route. The DDN IP routing tables are updated every ten seconds [Ref. 12].

d. Transmission Control Protocol (TCP)

TCP is characterized as connection-oriented service that provide reliable mechanisms for the transmission of data between entities in different computers. It ensures that data are delivered error free, in sequence, with no loss or duplication. TCP is one of the most complex communications protocols because it relieves higher level software of performing the communication functions; provides for high quality service, and deals with different communication services.

The basic operation of TCP can be described as follows. When data are passed from a transport user such as File Transfer Protocol (FTP) or a simple mail transfer protocol (SMTP), TCP encapsulates those data into a PDU containing the user data and TCP header with control information such as the destination address. PDUs being transmitted are numbered sequentially and subsequently acknowledged, by number, by the destination, TCP module. Thus, PDUs that arrive out of order can be reordered based on sequence number. If a PDU is lost, it will not be acknowledged and the source TCP module must retransmit it.

In addition to the basic service, TCP offers a number of other services. A security classification or range may be used to label data provided to TCP. Another service is the quality of service. A transport user can specify the quality of transmission service to be provided. TCP will attempt to optimize the use of the IP and the network resources. Parameters that may be specified include precedence and delay.

Urgent delivery is another service that can be specified to TCP. TCP then will attempt to transfer data as fast as possible. At destination, TCP will notify the user via the use of interrupt mechanisms. [Ref. 16:p. 54]

e. File Transfer Protocol (FTP)

This protocol enables an on-line user to interactively transfer a file or a portion of a file from one system to another. Three possibilities exist for user to transfer a file. First, a user at system A may wish a file in system B to be transferred to system A. In this case, the user must have local access to the content of the file. Second, a user at system A may wish to send a file from system A to system B. The third possibility is that a user at system A may request a file be exchanged between system B, and a third system, C. This involves the FTP entities at A, B, and C.

The operation of FTP involves first the host operating system in order to facilitate the user's communication with FTP via the use of its input/output (I/O) drivers. This provides a user interface to accept requests from an interactive user or a program at the requesting system. The remote FTP in a file tr^nsfer in this case, doesn't interact with a user. Next, FTP uses the services of TCP in order to communicate with other FTPs to achieve file transfer. Finally, FTP must have an interface with the local file management system to enable it to get at the file to be transferred. Figure 3-8 depicts FTP interaction with the three entities.

FTP offers a numbers of options. Controlled user access is provided by FTP; a user must have an authorized password/identification for that system. Also, data compression can be invoked to reduce communications cost. In addition, text files that use ASCII or EBCDIC character codes may be transferred. Finally, a transparent bit stream type can be employed to allow any sort of data or text file to be sent [Ref. 20:p. 32].

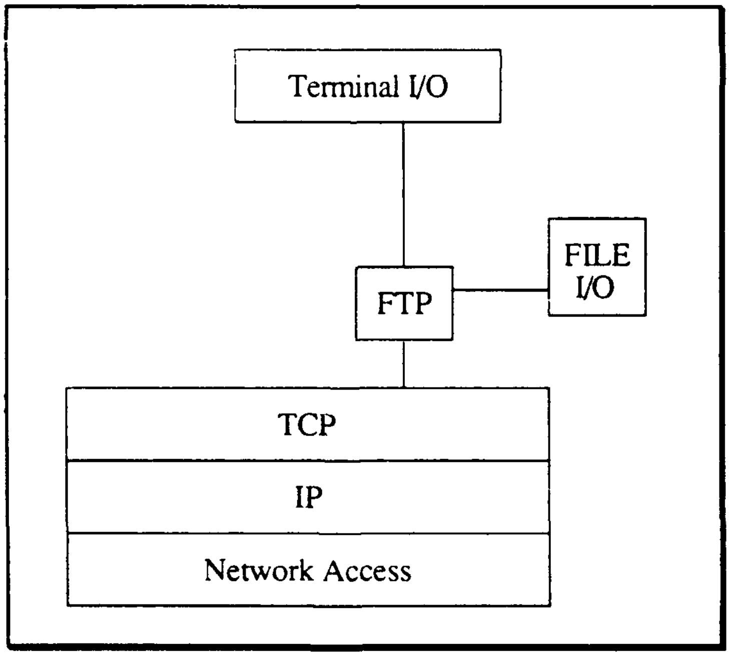


Figure 3-8. Conceptual Structure of the FTP

f. *Simple Mail Transfer Protocol (SMTP)*

This protocol provides the network electronic mail facility. Each authorized user on the system has a mailbox. A user can send a message by placing it in the mailbox of another user, and receive mail in the user's own mailbox. These mailboxes are maintained by the file management system on the host. Each mailbox maintains a directory of the messages text files. Users may use the system editors or word processors. A single system facility is known as the native mail facility. Figure 3-9 represents a conceptual structure of the electronic mail system [Ref. 16:p. 122]. This facility, of course, is provided as an application on a particular system.

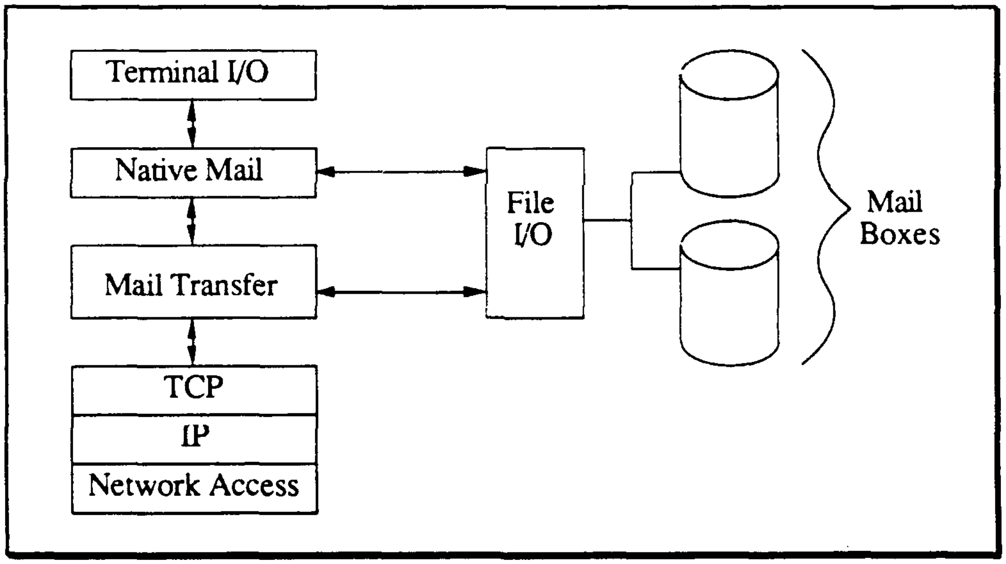


Figure 3-9. The Electronic mail (SMTP) as Used in DDN

The basic service of SMTP can be used among separate systems. A user can send mail not only to other users on the same system, but to users anywhere in the DDN. SMTP accepts messages prepared by the native mail entity and delivers them to that entity. SMTP uses TCP to send and receive messages :ross the DDN. There is no user interface specified by SMTP.

Therefore, the user sees the same interface whether sending local mail or remote mail.

g. TELNET

TELNET is a protocol that specifies how different types of terminals be linked to applications throughout the DDN. It specifies the network standard terminals so that a variety of terminals can be connected to a variety of hosts. It also takes into consideration different terminal characteristics such as line width, page size, full-duplex or half-duplex, remote and local echo.

Moreover, TELNET interacts directly with TCP to provide reliable data transfer. Finally, TELNET supports a user to control an application in a remote system transparently through his/her own terminal. TELNET protocol provides a binary transmission option to allow not only asynchronous scroll mode terminals but also any kind of terminal data transparently without the need of converting to a network standard.

TELNET is usually configured in two modules, as shown in Figure 3-10, user TELNET and server TELNET. User TELNET interacts with the terminal I/O module of the host operating system. It converts the characteristics of real terminals to the network standard virtual terminal and vice versa. Server TELNET interacts as terminal handler for process and applications. In the latter case, remote terminals appear as local to the process or application invoked [Ref. 20:p. 34].

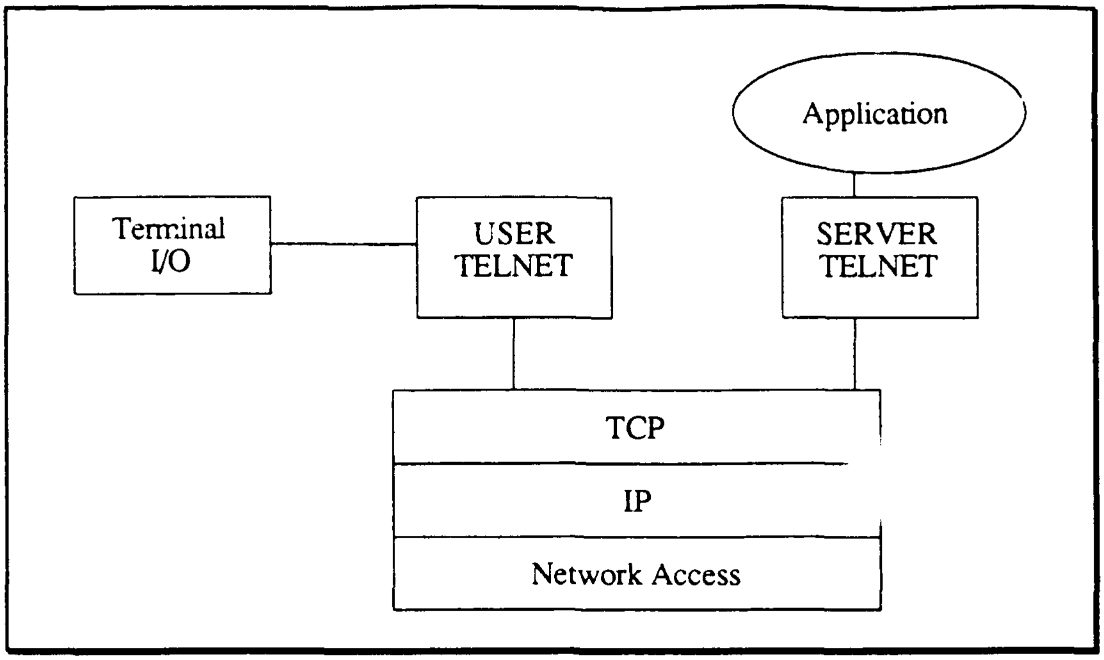


Figure 3-10. TELNET Protocol Conceptual Structure

E. DDN FEATURES

The DDN has several features that contribute to its success and will lend smoothly into future expansion. The most important ones are survivability, availability, and security.

1. Survivability

No system is invulnerable, but DDN has the ability to function during crisis providing vital DOD communications afte: a disaster has occurred. Disasters may include natural types such as earthquakes and severe storms. The other type of disaster is enemy-inflicted disaster including conventional or nuclear attacks.

In addition to the physical security measures that are taken by the users of DDN to protect their communications equipment, PSNs of the shared backbone of DDN are often collocated wit. the subscriber's equipment within a military installation. As a result, these PSNs benefit from military installation protection.

Moreover, several survivability features are inherent to the DDN structure. These features include (a) redundancy, (b) dynamic adaptive routing (c) precedence, (d) dispersion, (e) graceful degradation, (f) reconstitution, (g) hardening [Ref. 15:p. 13-24].

a. *Redundancy*

Most of the critical components of DDN equipment have spare parts and redundant capability. The packet switching nodes within DDN provide as backup spares for each other while each PSN can process traffic from any source.

The access network of the DDN has redundant features as well. A procedure called dual homing allows critical users to reach the DDN through secondary lines which are connected to a second PSN.

b. *Dynamic Adaptive Routing*

This feature of the DDN enables data packets to avoid damaged nodes and/or lines. This feature greatly enhances the survivability of the DDN by allowing traffic to continue to flow over remaining portions of the network.

c. *Precedence*

The DDN establishes precedence to ensure that critical users receive the best possible network service under stress conditions. This feature employs the preemption mechanisms which are related to the congestion detection and avoidance [Ref. 19].

Each PSN in DDN processes messages according to precedence procedures as well as to time in the system. During peacetime, precedence mechanisms ensure faster delivery of time-sensitive traffic even if the network is congested. During a crisis, precedence procedures allow critical users to designate which traffic gets priority on whatever network resources remain intact. Figure 3-11 illustrates the above survivability features [Ref. 22].

d. Dispersion

The DDN switching nodes are geographically distant from each other. This dispersion enhances survivability while damaged portions of the network are easily isolated. The large geographic spread of DDN backbone elements minimizes the damage that any one disaster can inflict.

e. Graceful Degradation

Damaged elements of the DDN do not prevent the entire network from functioning. DCA employs centralized regional centers to monitor the status of DDN at all times. These monitors will assist with congestion and equipment problems. Should a part of the network be destroyed, the monitoring centers would use the remaining resources to configure a limited network.

f. Reconstitution

Contingency plans must be prepared to ease restoration efforts in case the DDN should become disabled. As those plans are invoked to keep the network operating on a limited basis, DCA starts restoring DDN to its full capability. DCA has five mobile switching centers that will be deployed to provide packet switching during repairs of permanent node sites. This process will increase the DDN flexibility during peacetime as well as war time.

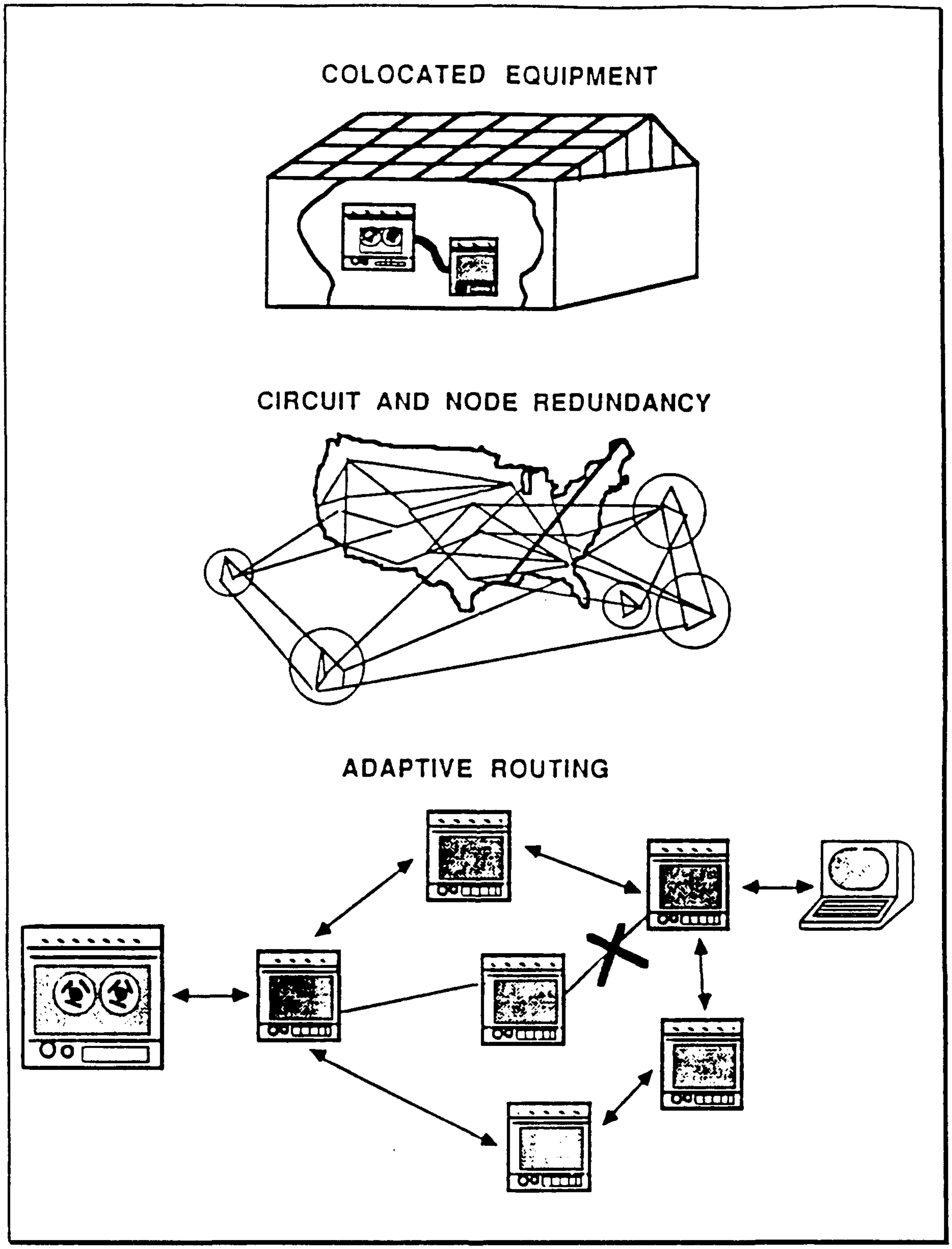


Figure 3-11. DDN Survivability Features

g. Hardening

Building structural reinforcement provides some protection against enemy bombs. As previously mentioned, most of the DDN switching nodes and access equipment are collocated within a subscriber's facilities. All DDN components will have electromagnetic shielding and power surge protection against High Altitude Electromagnetic Pulse (HEMP).

In addition, the diversity of transmission media reduces the network's vulnerability to carriers problems, acts of sabotage, jamming and other electronic countermeasures (ECM) attacks and to other threats ne transmission base [Ref. 19].

All these survivability features enable DDN to function under various stress levels. These levels of stress are threats defined by the U.S. Joint Chiefs of Staff to ensure that survivability measures are met at the network level, system level, node level, and user level. The primary DDN roles in response to each stress level, major threats, and the survivability features are described in Table 3-ـ .Ref. 19:p. 150].

2. Availability

It is the mission of DDN to provide communications capabilities for DOD continuously in order to support real-time handling of all user traffic. The DDN backbone must be always available for access to host computers and user terminals. The availability of the network recorded a 99.30% for single-homed subscribers and 99.95% for dual-homed subscribers [Ref. 22]. This high percentage availability of the DDN is directly affected by three factors (1) reliability (2) delay, and (3) accuracy.

TABLE 3-2. DDN SURVIVABILITY UNDER DIFFERENT THREAT STRESS LEVELS

STRESS LEVEL	RANK	PRIMARY DDN ROLE	MAJOR THREATS	SURVIVABILITY FEATURES
A. Peacetime readiness	4	Support Command and Control and Intelligence traffic and DOD Administrative users	1. Random failures due to wearout of hardware components, residual software bugs, and external failures (e.g., power failure)	Network design - Network dispersion - Redundancy - Dynamic routing
B. Crisis and Pre-Attack, and Theater Non-Nuclear War	1	Above, plus surge requirements, handled according to established procedures	1. Surge in traffic load 2. Random failures 3. Sabotage 4. use of conventional weapons against the network elements in Europe	As above, and - Precedence preemption - Reconstitution nodes - Preplanned alternative circuit routing - Preplanned rehoming
C. Early Trans Attack (Few Weapons Possibly EMP)	2	Support Critical C-2 Traffic	1. EMP 2. Use of few nuclear weapons against the system assets in CONUS	As above, and - EMP hardening - Site hardening when collocated with hardened users - User COOP plans
D. Massive Nuclear Attack	5	Support Critical C-1 Traffic as able	1. Extensive use of nuclear weapons against the systems assets in CONUS	As above
E. Post Attack	3	Possess capability to initiate reconstitution from the surviving fragments of the DDN I. Support the DCS as part of the NCS in reconstituting national communications	1. possible use of few nuclear weapons against the surviving system elements	As above, and - Rehoming existing ISA AMPES & interconnecting them - Reconstitution HC

DCS: Defense Communications System
NCS: Network Communications System
ISA AMPES: Interservice Agency Automated Message Processing Exchange
MC: Monitoring Center

First, the DCA has set minimum threshold standards for the operational components of DDN. The minimum acceptable measure of reliability for the PSNs is 98.5%. The performance of the PSNs has exceeded 99.45%. The interswitch trunks also achieved a 98.33% performance reliability level exceeding the minimum acceptable threshold of 97%. The composite system performance of the DDN backbone, PSNs plus the interswitch trunks, recorded a reliability level of 98.89%.

Second, the amount of delay for a message to reach its destination is an important factor of the availability of the DDN. Messages sent are broken into packets with control information added to them. This addition causes overhead that is reflected on the time it takes to reach the destination.

The average source-to-destination time for low precedence DDN traffic within the U.S. is less than 200 milliseconds. But this speed does not reflect accurately the user's situation since there are peak working hours during which response time might not be acceptable. DCA encourages users to postpone non-interactive, low priority traffic to slack periods in order to minimize the overall system delay.

Third, the accuracy of the DDN is reflected by the measures taken to ensure error-free transmission through the access devices, access lines, switching nodes, and interswitch trunks.

DDN uses techniques called 16-bit cyclic Redundancy Checks (CRC) to detect errors in the access and trunk circuits. CRC requires the transmitter to attach a sequence of bits to make the entire frame exactly divisible by a predetermined number. The receiver divides the incoming frame by this same number. If there is no remainder, the receiver does not request a retransmission.

In addition, DDN must detect errors during data processing. The subscriber computers use an error detecting mechanism that performs a summation operation on the bits. These end-to-end accuracy checks are known as 16-bit check sums. DCA projects that the probability of undetected error is 4.2×10^{-18} and the probability of misdelivering a packet is 5.5×10^{-12} [Ref. 14]. Accordingly, an error would skip through the network undetected only once every 174,000 years.

3. Security

The defense community classifies its information according to its sensitivity. DOD assigns security clearances that dėsignate the highest classification level of information that each person or equipment can handle or process. DDN security concerns are related to communications security and computer security.

a. Communications Security

This involves the process of recurring information as it is transmitted from one location to another. Encryption has been the primary method for establishing communications security. In addition, metallic shielding of equipment, known as TEMPEST, is the DOD technique that is used to contain signals.

Moreover, DOD has maintained the separation of DOD agencies at different classification levels in order to enhance security. The DDN segments that support classified data employ the Blacker front-end computer devices to ensure encryption of data sent among host computers. Blacker devices installed between switching nodes enable separate classified networks to use the same backbone nodes and trunk circuits. Eventually, information will flow from a host in one segment of DDN to a host in another segment, by the end of 1992, by using the guard gateway equipment.

DDN has incorporated backbone link encryption by installing KG-84 cryptographic equipment on all trunks among PSNs and on all access lines between computers and the backbone network. Terminal link encryption is also available to attach users to access lines. The installation of these encryption devices, called LEADs, at user terminals provide protection of data as it travels to host computers.

b. Computer Security

The major function of the computer security is to safeguard data processors from outside tampering and unauthorized access. Physical security measures provide some protection against outsiders gaining access to terminals. However, DDN can be reached via dial-in telephone lines without even being on a military base.

Therefore, the actual computer security features of the DDN include user identification and authentication mechanisms. Access control systems requires a user to enter an identification code and a password. The identification code could be published for electronic mail addressing. But passwords are only known to authorized individuals.

Users accessing DDN through terminals linked to TACs are required to input to the TAC a TAC user ID and an access code before even logging into their host computer systems.

F. DDN USES BY THE MILITARY

Since the DDN supports a wide range of hardware and utilizes X.25 protocol, it allows a variety of applications to be on-line. The U.S. Marine Corps has its logistics and administrative systems on the network. The Air Force has upgraded its personnel system for operations using the DDN, and has its supply system on the network to provide worldwide coordination among all Air Force bases. In addition, the Navy Regional Data Automation Centers and the Army Inspector General MIS system are connected to DDN.

Many organizations within the DOD use the DDN for electronic mail. Furthermore, most armed forces management functions such as payroll, medical records, intelligence, and command, control and communication (C3) are maintained on the DDN.

The DDN reliability and security features made it possible to establish telecommunication links between contractors and the DOD. Information can be transmitted securely between private firms and the different agencies within DOD. It is expected that DDN will be used for the delivery of software products as well as correspondence with contracting agencies [Ref. 18:p. 122].

IV. THE PROPOSED MODA MODEL

A. MODA GOALS AND OBJECTIVES

The major mission of the Ministry of Defense and Aviation (MODA) of Saudi Arabia is to defend the country against aggression. Therefore, the objective of MODA DDN is to improve combat readiness capability through the rapid exchange of urgent and important messages among the Armed Forces. This will result in good decision making and will contribute to interservice cooperation regarding sharing of information, joint operations, and supply cooperation.

Another objective of MODA DDN is office automation through the application of computer and communications technology. This will contribute to the productivity of clerical and administrative office work. In addition, MODA DDN can serve as a general purpose computer network for information exchange, and experimental or research network.

According to the objective set forth, several goals are desirable in the proposed MODA model. These include, but are not limited to, efficiency, security, reliability, survivability, flexibility, and cost-effectiveness.

The suggestion is to model the proposed computer communication network for the MODA DDN using the current technology of the U.S. DDN discussed in Chapter III. The following section will provide an overview of the network design which can be applied to the MODA DDN. It must be emphasized that this paper does not provide a solution to the design problem but, rather, the general concepts are presente .

B. NETWORK DESIGN: AN OVERVIEW

Generally, a computer and data communications network is seen by the users as a "transport mechanism" to pass data from one user to another. But the internal environment of the network includes switches and transmission lines among the switches. The number and capacity of these costly resources have to be limited by the budget, users' demand, and possible future demand.

When dealing with switched data networks, the user must balance costs of services with network capabilities and reliability. Furthermore, design considerations such as connectivity, structure of the network, routing, the type of community the network is trying to serve, and finally, how the network is controlled, are of paramount importance. Figure 4-1 summarizes these design considerations [Ref. 23:p. 41].

Usually, two approaches are commonly used in designing a computer communication network. The first approach is the cost minimization where the network designer tries to determine the most economical configuration of the network components that will meet the users' requirements. The second approach is to design a network with maximum reliability or survivability under a given set of stress level scenarios, subject to a given budget. Military networks are designed using the second approach.

1. Network Structure

The topology of the network directly affects it operation, reliability and its operating costs. Therefore, data links can be arranged in certain patterns in order to develop a specific topology.

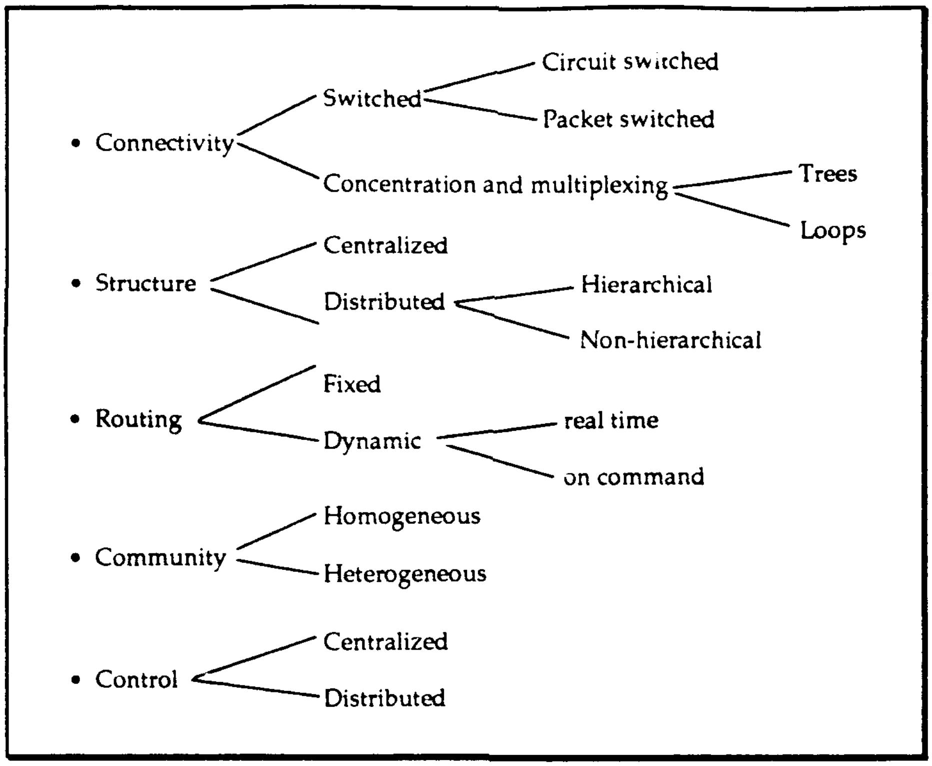


Figure 4-1. Design Consideration for Switched Data Network Development

a. Centralized Network

A centralized network is characterized by a central computer that functions both as a switch and as a data base host. Since each communications link is directly connected to the computer, there is no delay. The centralized topology (or star) is suitable where each terminal has a large volume of data traffic and must operate at 9,600 bits/s or another high data rate on a leased line [Ref. 25]. Figure 4-2a illustrates the configuration of a centralized network.

b. Distributed Network

This kind of network is characterized by the fact that the intelligence of the network, in the form of switching and processing, is distributed throughout the geographic area [Ref. 23]. This topology offers considerable advantages with respect to communications costs and time delays. See Figure 4-2b.

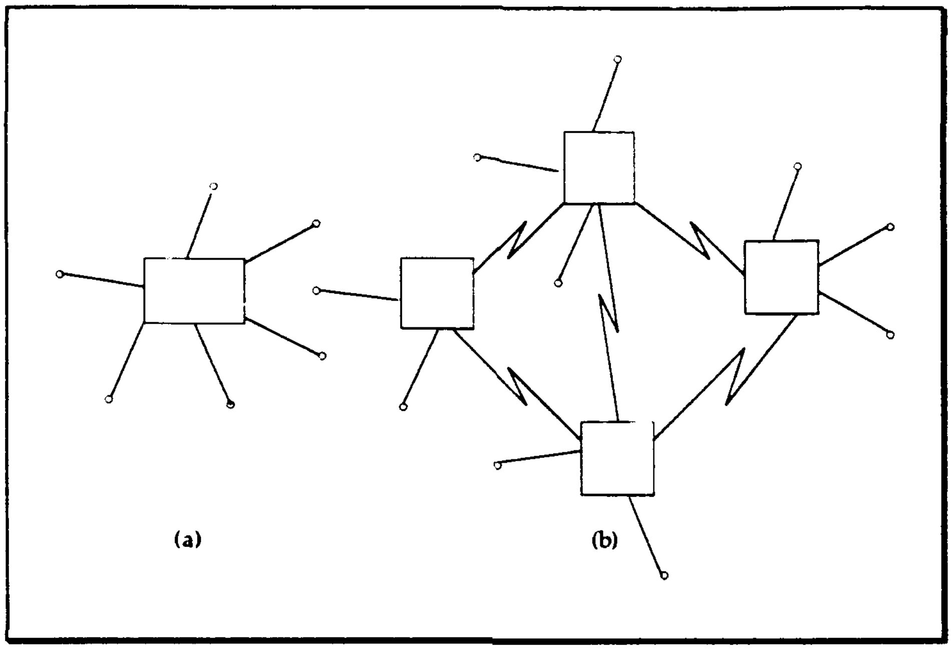


Figure 4-2. Network Topography. (a) Centralized (Star) (b) Distributed

By interconnecting computers, more links are available through which data transfer can occur. The rerouting capability of the network is enhanced in case a failure or outage of any channel between computers happens. In addition, overall network performance is improved by the additional transmission paths [Ref. 24].

Distributed networks can be further divided into hierarchical and non-hierarchical topologies. In the non-hierarchical distributed structure, each switch has a similar function in the network topology. And all of the network switches serve end users (host computer and/or terminals) and data transfer can occur through several switches en route to its destination.

On the other hand, hierarchical distributed networks use two different types of switches. One type is used to originate and terminate traffic and interface the users (host computers) to the network. The other type passes data traffic in a tandem manner between the switches [Ref. 23].

Hierarchical networks offer advantages in design and operation because of the separation of functions. Data routing is simplified since it is either routed directly or passed to the next level in the hierarchy. The major disadvantage of the hierarchical network is that if a line or a switch becomes inoperative, some of the users can be isolated from the network. Figure 4-3 illustrates the hierarchical and non-hierarchical network topologies.

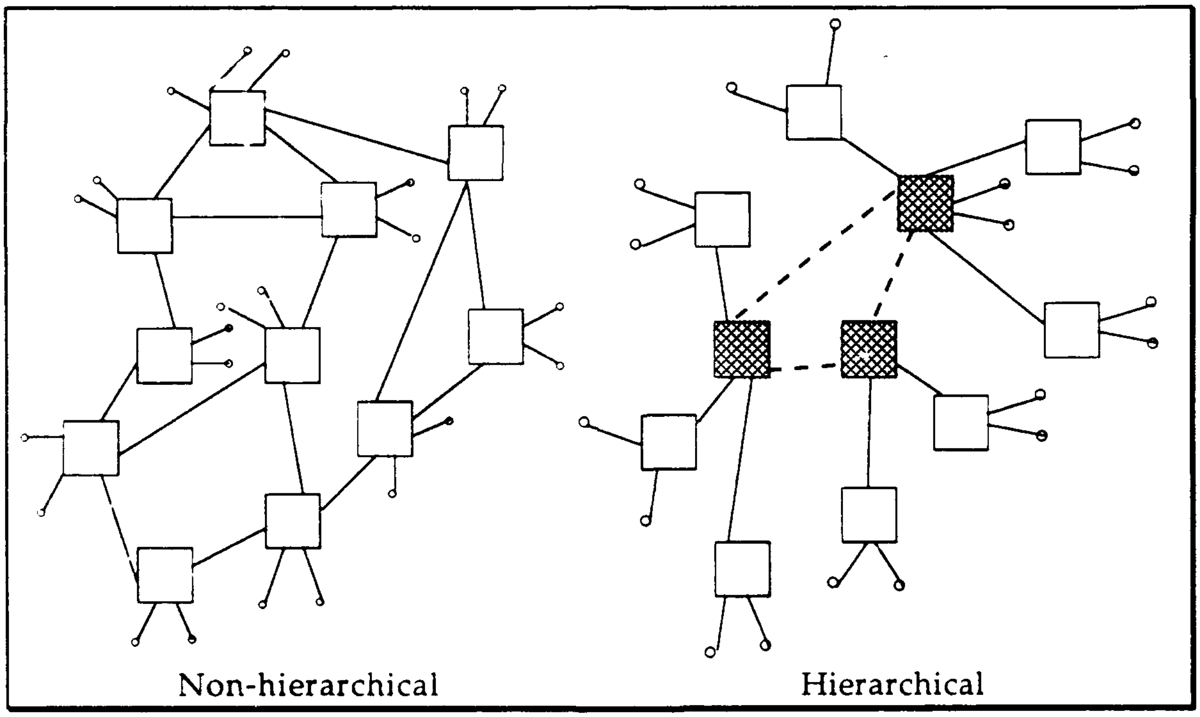


Figure 4-3. Hierarchical and Non-hierarchical Networks

One topological example of distributed networks is a loop (ring) network in which computers are connected via a loop or ring structure. This structure is economical when many remote terminals and computers are located close to one another. If remote terminals are geographically dispersed over long distances, line costs become very expensive [Ref. 25]. Ring structure is depicted in Figure 4-4.

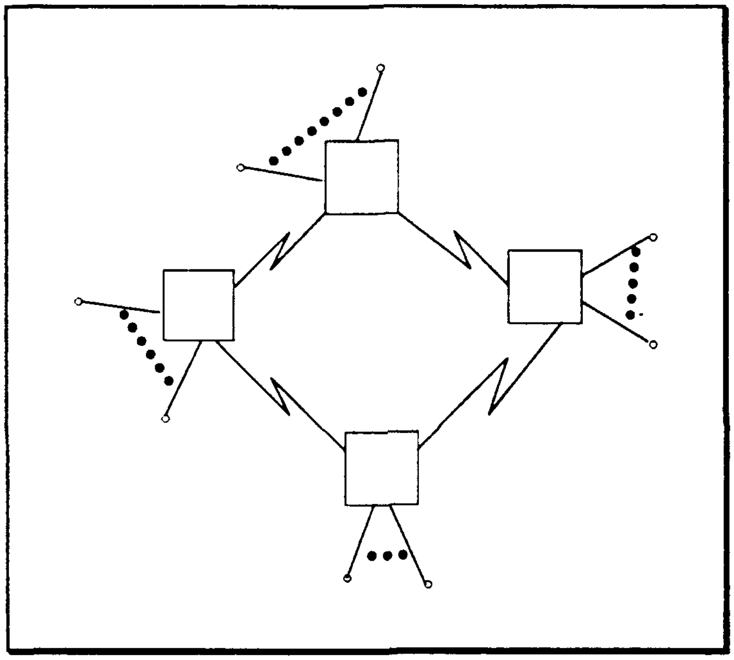


Figure 4-4. Ring (Loop) Topology

Due to a particular operating characteristic or traffic volumes, a mixed structure, combining all types of network topology, is possible as well. In any case, a design of the MODA DDN must ensure a degree of flexibility in the configuration and the capacity allocation so that the network can adapt to the true traffic load.

Several factors affect the decision for the topology to be used. Those include, but are not limited to, the size of the network, the path length between nodes, target reliability/availability level, number of channels available from carriers, manufacturer philosophy, and the size of the network [Ref. 26:p. 59].

2. Network Capacity Planning

Tiie key step in the MODA network design process it to identify the needs and requirements of the user community. This effort should include all the activities performed by the different users and the use of the various computer data bases in MODA.

The precise specification of the MODA user require. nts is actually an integral part of the network capacity planning process. This process determines the optimal, or, practically, the near-optimal network to meet the organizational future service needs. The responsibilities of the network-capacity planning can be summarized in four-stage methodology:

- Data collection,
- Establishing requirements,
- Design and optimization, and
- Implementation.

Figure 4-5 illustrates the process of the typical network-capacity planning and and a brief summary of the steps involved will follow [Ref. 26:p. 453-505].

In data collection, the characterization of past and present workloads must be developed statistically. This must include deadline requirements, application cycles, daily cycles, and service requirements. Another milestone in data collection is the identification of physical locations. This involves drawing maps with a large number of individual sites that are to be connected. Usually, the use of automated design tools is required.

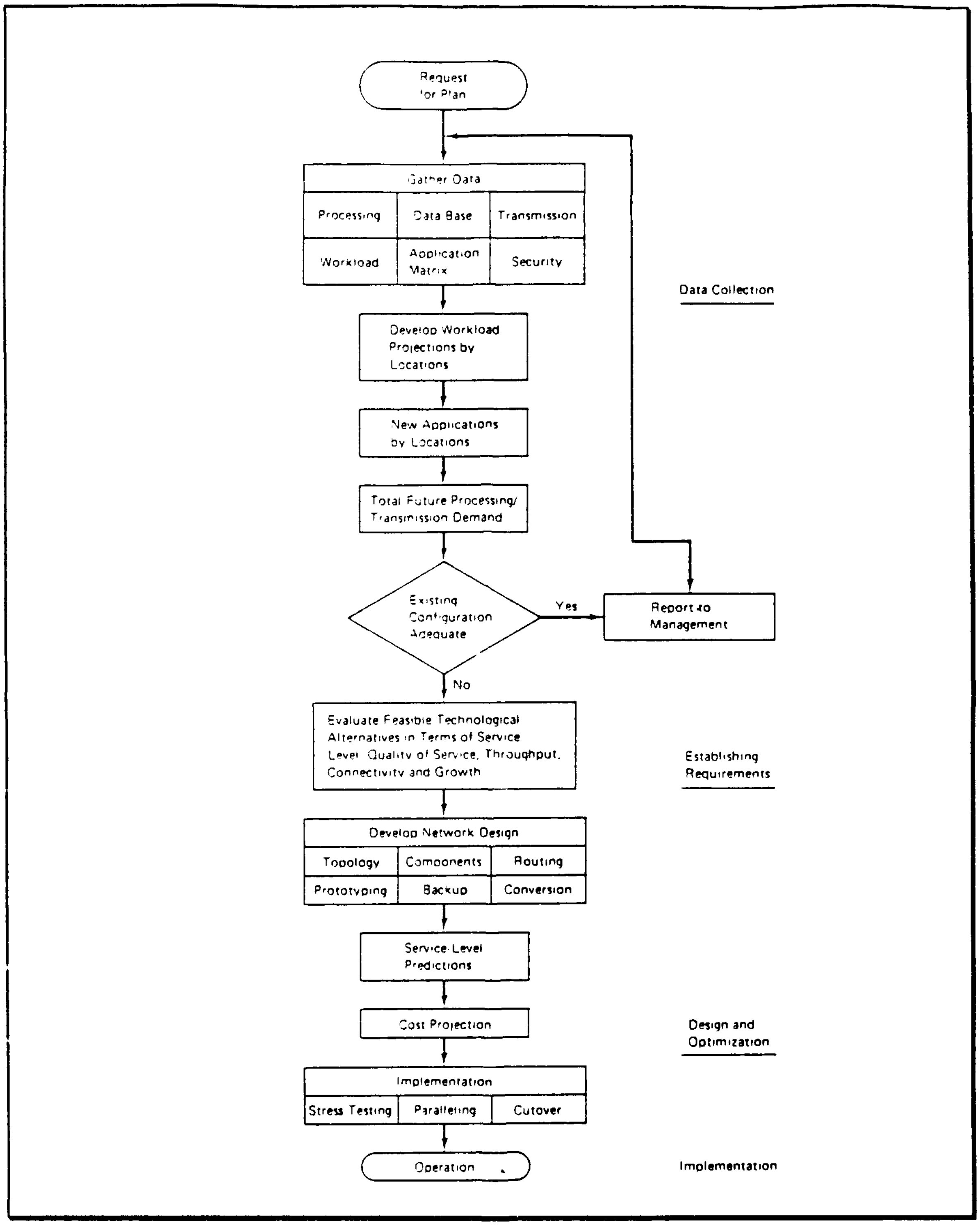

Request for Plan
Gather Data
Processing
Data Base
Transmission
Workload
Application Matrix
Security
Data Collection
Develop Workload Projections by Locations
New Applications by Locations
Total Future Processing/ Transmission Demand
Existing Configuration Adequate
Yes
Report to Management
No
Evaluate Feasible Technological Alternatives in Terms of Service Level Quality of Service, Throughput, Connectivity and Growth
Establishing Requirements
Develop Network Design
Topology
Components
Routing
Prototyping
Backup
Conversion
Service Level Predictions
Cost Projection
Design and Optimization
Implementation
Stress Testing
Paralleling
Cutover
Operation
Implementation

Figure 4-5. Network-Capacity Planning Process

Projecting application systems is a very important factor in data collection. It requires knowledge of the business and the changing environment around it. Management structure and reporting requirements are also identified at this stage.

Requirement specification is dependent on the collected data on past and present workload and estimated future networking requirements. As mentioned earlier, a user consists of hosts and terminals which require access to the network. Each device has a specific location, which can be represented by VH coordinate [Ref. 25], a set of protocols, and an interface speed. Another requirement is for each user to transfer data among each other. The amount of traffic sent may vary over time or may be associated with various scenarios such as a crisis scenario and a normal scenario [Ref. 11].

A User Requirement Data Base (URDB), similar to the U.S. DDN URDB, must be established to contain information about every user's hardware, its protocols, its application programs, its geographical location, and the computer system to which it belongs. Of course, a survey questionnaire should be designed to gather this information. Moreover, the survey should include information about the volume, type, and distribution of traffic from the user systems [Ref. 11].

Therefore, identification and projection of future workload can be determined. Then, the application impact across time is analyzed to determine the resource demand.

In order to come up with efficient and reliable computer communications network service, new technologies and services must be evaluated continually. The evaluation of new alternatives must be comprehensive enough to include the areas of distributed intelligence, office automation, LANS, local site optimization, communications services, and hardware equipment.

As the process goes on, a total figure on processing and transmission demand is achieved. Then the network-capacity planners compare the projected workload with the potential capacity to determine how well the present capacity can accommodate the service requirements. Design optimization and implementation will follow in the next section.

C NETWORK DESIGN PROCESS

The complete computer communication network design problem can be formulated as follows:

Given:

- terminal and host sites
- matrix of traffic requirements,
- delay requirements,
- reliability requirements,
- candidate topology for the backbone network, and
- cost elements.

Minimize:

- Total network Cost C where

$$C = \text{(backbone line costs)} + \text{(backbone PSNs costs)}$$
$$+ \text{(local network access line costs)} + \text{(local access hardware costs)}$$

Subject to:

The performance criteria such that throughput, delay, security, and reliability requirements are met.

Usually, the cost criteria establishes the objective function and the performance criteria determines the constraints [Ref. 26]. The major step in the evaluation of performance constraints is the formulation of a detailed traffic model. The model should specify a data rate during the network peak hours. The number and size of the packets transmitted to the network will vary according to the type of data, transactions (e.g., interactive, query/response, electronic mail, or file transfer). Then, the traffic data, augmented by the overhead which is produced from the application of the network protocols, is fed into computer simulation programs.

The design process is usually divided into a network access design, which is typically centralized systems, and a backbone design, which is generally a distributed network.

1. The Network Access Design

The design of network access deals with the placement of terminal concentrators (TACs or NACs), the connection of terminals to terminal concentrators, and terminal concentrators to PSNs. In addition, the determination of access line speeds is a critical part of the network access design [Ref. 11].

Operations Research computerized techniques and algorithms : often employed to facilitate the network access design problem. The goal is to achieve an objective function which will produce a cost-effective access design such that traffic, delay, security, and reliability requirements are met. Normally, these design constraints are set to some percentage of the known physical limits [Refs. 11, 24].

Throughout this process, the capacities of the network component, or the amount of traffic to a network component do not exceed the known limits. Therefore, a traffic-volume table can be constructed to determine the traffic-volume due to the homing of devices to PSNs. The traffic-volume table is depicted in Figure 4-6 [Ref. 25]. The totals for the columns with checkmarks are then used to compute a PSN-to-PSN traffic matrix. This matrix is a primary input to the backbone design process and it contains the traffic flowing at each priority level between each pair of PSNs. Moreover, it reflects the user data and protocol overhead and describes data rates and packet sizes [Ref. 11].

PSN #______

										AVERAGE			
	Calls/	Connect time/call		Total transit time		Msg/day to host		msg/day from host		characters/ msg		characters/ day	
	day	avg	peak	avg	peak	avg	peak	avg	peak	avg	peak	avg	peak
Total				√	√							√	√

Figure 4-6. Traffic-Volume Table

2. The Backbone Design

The backbone design of a computer communication network is characterized by parameters of cost, throughput, response time, and reliability. Therefore, the properties of both the PSNs and the network's topological structure must be considered [Ref. 24]. Some of the PSNs' important properties are:

- packet handling and buffering,
- error control,
- flow control,
- routing,
- PSN throughput, and

- PSN reliability.

Some of the topological characteristics are:

- link location,
- link capacity assignment,
- network response time,
- network throughput, and
- network reliability.

The selection of the most effective network architecture, which determines the number of levels and the type of access at each level, is the most important step in the design process of WANs. But there exists a number of alternatives for the backbone architecture within the packet switching concept as follows [Ref. 24]:

- **Line alternatives:** terrestrial links or combination of terrestrial and satellite links. The most cost-effective selection of the available service must be made for a given connection.
- **Node alternatives:** a backbone architecture with several conventional nodes in a fully interconnected cluster as a "super node" or with the higher nodal capacity of the multiprocessor switch.
- **Topological structure alternatives:** For small or medium-sized backbone network, the structure is homogeneous with identical software and compatible hardware at the PSNs. For larger networks, a two-level hierarchy within the backbone is more cost effective. The high-level net has higher node and link capacities than the low-level subnet. Subnets are connected to high-level net via gateways.

The most effective design techniques involve the heuristic application of a family of optimization procedures, human intuition, and engineering judgement. The goal is to reach the most cost-effective design which satisfies the throughput, delay, security, and reliability requirements. The approach employed is iterative [Ref. 11].

The technique starts with a candidate topology. Then, a mathematical model of the routing algorithm is used to assign flows to the link paths. Next, channel and PSN utilizations are computed. Using queueing theory, a mathematical model is derived to estimate packet delays. The candidate topology may be rejected if the trunk (channel) or PSN utilizations are to high or the average packet delay is too large. In addition, the candidate topology can be rejected if the reliability criteria are not met [Ref. 10].

Once the candidate topclogy is rejected, a new candidate is selected. The process is repeated until the desired optimal network is found and the cost can no longer be lowered.

Another important step in the network design process is to design the organizational and technical structure for restoring the communications network after breakdowns. This step is called contingency planning, which deals with situations where the network can be temporarily reconfigured to overcome individual network components, such as a failing line, a failing concentrator or PSN or an application failure and to allow for continued operation during the time taken to resolve the problem.

Along with contingency plans, backup and recovery plans should be prepared. These plans define the methods available to restore a part of the network or the entire network to an operational status. It contains detailed procedures to be used in fixing the problem.

Operational manuals should be also prepared based on the operational guidelines gathered during data collection and the hardware-software decisions from the requirement specification stage.

A step-by-step conversion plan must be taken into consideration. This means the operations of the present systems should continue until the new network has been thoroughly tested and proven.

Next, prototypes of the proposed network are presented for testing by the customer. Depending on the test results, the principal requirements may or may not be met. When requirements are not met, a return to the planning phase may be required to modify or include alternatives. It could also be necessary to go back to the design or nization and to evaluate additional topological alternatives. The process is iterative and finally, the prototype is tuned, results are evaluated, and decisions are made for further action to be taken.

The implementation is primarily based on conversion plans. It usually takes many steps, but the best way is to phase the implementation by location or application. It is recommended that actual volumes and transaction types be followed as closely as possible prior to cutover which must be prepared with great care. Cutover should be accomplished over night or over a weekend. CPM and PERT techniques are useful in timing. In addition, stress testing is performed to test not only the fuctionality but also the service level requirements. By using as many of the new network's facilities as possible, the chances of identifying potential bottlenecks are significantly improved.

Operation and communication networks personnel must be trained to face all possibilities before actual cutover. Technical support, administrative, and help-desk personnel should be prepared as well.

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This thesis has provided the fundamental concepts for designing a computer communications network for the MODA. The goal is to establish an interoperable wide are network for MODA which will evolve into an efficient Integrated Computer Communications Network (ICCN). Ultimately, the Saudi DDN will serve the national defense.

Because of lack of actual data about the MODA requirements, this study focused on the conceptual framework for building a data network. Therefore, this study should serve as a guideline and not as a solution for constructing a computer communications network that is needed to connect all of the Saudi armed forces.

B. CONCLUSIONS

Based on the information provided in this study, the following conclusions can be drawn:

(1) A computer communications network, such as the U.S. DDN, can be used operationally for military applications and it is performing very well.

(2) Packet-switched networks provide for valuable networking and resource sharing.

(3) The Saudi MODA and the four services of the armed forces, Army, Air Force, Navy, Air Defense and their subordinate commands and units, will tremendously benefit from improved networking capabilities within each service and among the four services.

(4) Increased sharing of resources and ideas within each service and among the four services will be beneficial to the overall operations of MODA.

(5) The computer communications network can be easily expanded to enhance administrative communications capabilities.

C. RECOMMENDATIONS

The findings of this study result in recommendations related to two different categories of the overall integrated computer communications network. The first category relates to the development of the network itself and the second one relates to the user community of the Saudi MODA.

1. The Network-related Recommendation

It is strongly recommended that the following basic elements be considered during the development of the MODA DDN:

(1) The MODA Defense Data Network (DDN) must be designed to meet MODA goals and objectives.

(2) The MODA DDN must be designed with careful considerations of all circumstances and possible consequences.

(3) Network security and survivability must be a primary consideration throughout the development.

(4) MODA currently uses various communications links. But dedicated data communications channels are needed as in the U.S. DDN.

(5) Many types of computers can be used for PSNs, TACs, NMCs, gateways, hosts, and terminals. MODA should acquire equipment which offers high performance with the least cost.

(6) MODA will need various types of software for the proposed DDN backbone and the access network in order to communicate across the network and provide access for the users. Standard software should be purchased or developed to provide the interoperability required within and among the services.

2. User-related Recommendations

Although all users within the defense community should be taken into consideration when planning for the development of the network, the following recommendations should be emphasized:

(1) Each command or unit which happens to be near an available MODA host computer or TAC must investigate the possibility of accessing the network so that the DDN capabilities can be used.

(2) The armed forces heads and communications managers should familiarize themselves with DDN operations and communications procedures.

(3) MODA personnel involved in the transition to the proposed MODA DDN should study the DDN concepts and apply them wherever applicable during network development.

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